Branch: MECHANICAL ENGINEERING

Semester: 6th Sem

Subject: POWER STATION ENGINEERING

Faculty: ER. SANJAY KUMAR PANIGRAHY

ER. JAGNYA PRASAD BEHERA

CHAPTER-I
INTRODUCTION

Energy:

Energy possesses the ability to produce a dynamic, vital effect. Energy exists in various forms. e.g. mechanical, thermal, electrical etc. One form of energy can transform to other by suitable arrangements.

Power:

Any Physical unit of energy when divided by a unit of time automatically becomes a unit of power. Power can be defined as rate of flow of energy and can state that a power plant is a unit built for production and delivery of flow of mechanical and electrical energy.

With the advancement of technology the power consumption is rising steadily. This necessitates that in addition to the existing source of power such as coal, water, petroleum etc. other source of energy should be searched out and new and more efficient ways of producing energy should be decided.

SOURCES OF ENERGY:

The various sources of energy are:

Fuels- 1. Solids-Coal, Coke Anthracite etc.
2. Liquids-Petroleum and its derivates
3. Gases-Natural gas, blast furnace gas etc

Energy stored in water
Nuclear energy
Wind energy
Solar energy
Tidal energy
Geothermal energy
Thermoelectric power

Fuels:

Fuels may be chemical or nuclear. A chemical fuel is a substance which releases heat energy on combustion. The principal combustible elements of each fuel are carbon and hydrogen.

Solid Fuels:

Coal:

Coal is the largest source of energy for the generation of electricity worldwide, as well as one of the largest worldwide anthropogenic sources of carbon dioxide releases. Its main constituents are carbon, hydrogen, oxygen, nitrogen, sulphur, moisture and ash. Coal passes through different stages during its formation from vegetation. Coal has been used as an energy resource, primarily burned for the production of electricity and/or heat, and is also used for industrial purposes, such as refining metals. A fossil fuel, coal forms when dead plant matter is converted into peat, which in turn is converted into lignite, then sub-bituminous coal, after that bituminous coal, and lastly anthracite. This involves biological and geological processes that take place over a long period.

[1]

Peat:

It is the 1st stage of formation of coal from wood. It contains huge amount of moisture and therefore it is dried for 1 to 2 months before it is put to use. It is used as domestic fuel.

Lignite and Brown Coals:

These are intermediate stages between peat and coals. They have a woody and often a clay like appearance associated with high moisture, high ash, low heat contents. Lignite are usually amorphous in character and impose transport difficulties as they break easily. They burn with a smoky flame.

Bituminous Coal:

It burns with long yellow and smoky flames and has high percentages of volatile matter.

Semi bituminous Coal:

It is softer than anthracite and burns with a very small amount of smoke. It has tendency to break into small sizes during storage and transportation.

Semi Anthracite:

It has less fixed carbon and less luster as compared to true anthracite and gives out longer and more luminous flames when burnt.

Anthracite:

It is very hard coal and has a shining black luster. It ignites slowly unless the furnace temperature is high. It burns either with very short blue flames or without flames and very suitable for stem generation.

Wood charcoal:

It is obtained by destructive distillation of wood. During the process the volatile matter and water are expelled. The physical properties of the residue(Charcoal) however depends upon the rate of heating and temperature.

Coke:

It consists of carbon, mineral matter with sulphur and small quantities of hydrogen, nitrogen and phosphorus. It is solid residue after the destructive distillation of coals. It is smokeless and clear fuel and can be produced by several processes. It is mainly used in blast furnace to produce heat.

Briquettes:

These are prepared from fine coals by compressing the material under high pressure.

Analysis of Coal:

The following two types of analysis are done on the coals:

1. Proximate analysis
2. Ultimate analysis

In proximate analysis individual elements are not determined, only the percentage of moisture, volatile matter, fixed carbon and ash are determined. In ultimate analysis the percentage of various elements are determined.

Properties of Coal:

Energy content or heating
value Sulphur content
Burning Characteristics
Grind ability
Weather ability
Ash softening temperature
A good coal should have:-
Small percentage of sulphur
Good burning characteristics

Liquid Fuels:

The chief sources of liquid fuels are petroleum which is obtained from wells under the earth's crust. These fuels have proved more advantageous in comparison to solid fuels.

Advantages:

Require less space for storages
Higher calorific values
Easy control of
consumption Staff economy
Absence of danger from spontaneous combustion
Easy handling and transportation
Cleanliness
No ash problem
Non-deterioration of the oil in storage

Petroleum:

These are different opinions regarding the origin of petroleum. Now it is accepted that Petroleum has originated probably from organic matter like fish and plant life etc., by bacterial action or by their distillation under pressure and heat. It consists of a mixture of gasses, liquids, and solid hydrocarbons with small amount of nitrogen and sulphur compounds.

Gaseous Fuels:

Natural Gas: The main constituents of natural gas are methane and ethane. Natural gas is used alternately or simultaneously with oil for internal combustion engine.

<u>Advantages</u>:

Better control of combustion
Much less excess air is needed for complete combustion
Economy in fuel and more efficiency of furnace operation
Easy maintenance of oxidizing or reducing atmosphere
Cleanliness
No problem of storage
Distribution over a wide area is easy

Important Properties:

Heating Value
Viscosity
Specific
gravity Density
Diffusibility

Flowing Stream of Water:

The energy contained in flowing stream of water is a form of mechanical energy. It may exist as the kinetic energy of a moving stream or potential energy of water at some elevation with respect to a lower datum level, an example of which would be the water held behind a dam.

Solar Rays:

Solar energy, radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic, concentrated solar power, solar architecture and artificial photosynthesis. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air. Active solar technologies encompass solar thermal energy, using solar collectors for heating, and solar power, converting sunlight into electricity either directly using photovoltaic (PV), or indirectly using concentrated solar power.

Wind Power:

Airflows can be used to run wind turbines. Modern utility-scale wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5–3 MW have become the most common for commercial use; the power available from the wind is a function of the cube of the wind speed, so as wind speed increases, power output increases up to the maximum output for the particular turbine.

Ocean Tides and Waves:

Wave, tidal and ocean energy technologies are just beginning to reach viability as potential commercial power sources. Waves are produced by winds blowing across the surface of the ocean. However, because waves travel across the ocean, their arrival time at the wave power facility may be more predictable than wind. In contrast, tidal energy, which is driven by the gravitational pull of the moon and sun, is predictable centuries in advance. The technologies needed to generate electricity from wave and tidal energy.

Geothermal Energy:

Geothermal energy is from thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. Earth's geothermal energy originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%).The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface.

Concept of Power Station:

A power station (also referred to as a generating station, power plant, powerhouse or generating plant) is an industrial facility for the generation of electric power. Each power station contains one or more generators, a rotating machine that converts mechanical power into electrical power by creating relative motion between a magnetic field and a conductor. The energy source harnessed to turn the generator varies widely. Most power stations in the world burn fossil fuels such as coal, oil, and natural gas to generate electricity, and some use nuclear power, but there is an increasing use of cleaner renewable sources such as solar, wind, wave and hydroelectric.

Central Power Station:

The Central Power Station is the distribution point for campus utilities, including electricity, heat, cooling, 60 -pound steam, compressed air, and natural gas. It has co-generation capability, which allows it to produce up to 30% of the campus electrical demand as a by-product of steam production. The Central Power Station staff is responsible for the maintenance of 5 miles of tunnels, through which the utilities are distributed. The Central Power Station is presently undertaking an extensive series of upgrades to increase its efficiency and its capacity to serve new buildings and planned future development on the east side of campus. Reductions in energy consumption and environmental impact are major considerations in the design.

Captive Power Station:

Captive Generating plant means a power plant set up by any person to generate electricity primarily for his or her own use and includes apower plant set up by any co-operative society or association of persons for generating electricity primarily for use of members of such co-operative society or association.

Types of Power Plants:

Coal Based Thermal Power Plants:

In thermal power stations, mechanical power is produced by a heat engine that transforms thermal energy, often from combustion of a fuel, into rotational energy. Most thermal power stations produce steam, so they are sometimes called steam power stations. Not all thermal energy can be transformed into mechanical power, according to the second law of thermodynamics; therefore, there is always heat lost to the environment. If this loss is employed as useful heat, for industrial processes or district heating, the power plant is referred to as cogeneration power plant or CHP (combined heat-and-power) plant. In countries where district heating is common, there are dedicated heat plants called heat-only boiler stations. A coal-fired power station produces heat by burning coal in a steam boiler. The steam drives a steam turbine and generator that then produces electricity The waste products of combustion include ash, sulphur dioxide, nitrogen oxides and carbon dioxide. Some of the gases can be removed from the waste stream to reduce pollution.

Nuclear Power Plants:

Nuclear power plants use a nuclear reactor's heat that is transferred to steam which then operates a steam turbine and generator. The conversion to electrical energy takes place indirectly, as in conventional thermal power plants. The heat is produced by fission in a nuclear reactor (a light water reactor). Directly or indirectly, water vapor (steam) is produced. The pressurized steam is then usually fed to a multi-stage steam turbine. After the steam turbine has expanded and partially condensed the steam, the remaining vapor is condensed in a condenser. The condenser is a heat exchanger which is connected to a secondary side such as a river or a cooling tower. The water is then pumped back into the nuclear reactor and the cycle begins again. The water-steam cycle corresponds to the Rankine cycle. A nuclear reactor is a device to initiate and control a sustained nuclear chain reaction. The most common use of nuclear reactors is for the generation of electric energy and for the propulsion of ships. The nuclear reactor is the heart of the plant. In its central part, the reactor core's heat is generated by controlled nuclear fission. With this heat, a coolant is heated as it is pumped through the reactor and thereby removes the energy from the reactor. Heat from nuclear fission is used to raise steam, which runs through turbines, which in turn powers either ship's propellers or electrical generators. Since nuclear fission creates radioactivity, the reactor core is surrounded by a protective shield. This containment absorbs radiation and prevents radioactive material from being released into the environment. In addition, many reactors are equipped with a dome of concrete to protect the reactor against both internal casualties and external impacts.

Diesel Power Plants:

Diesel power plant’s is in the range of 2 to 50 MW capacity. They are used as central station for small or medium power supplies.

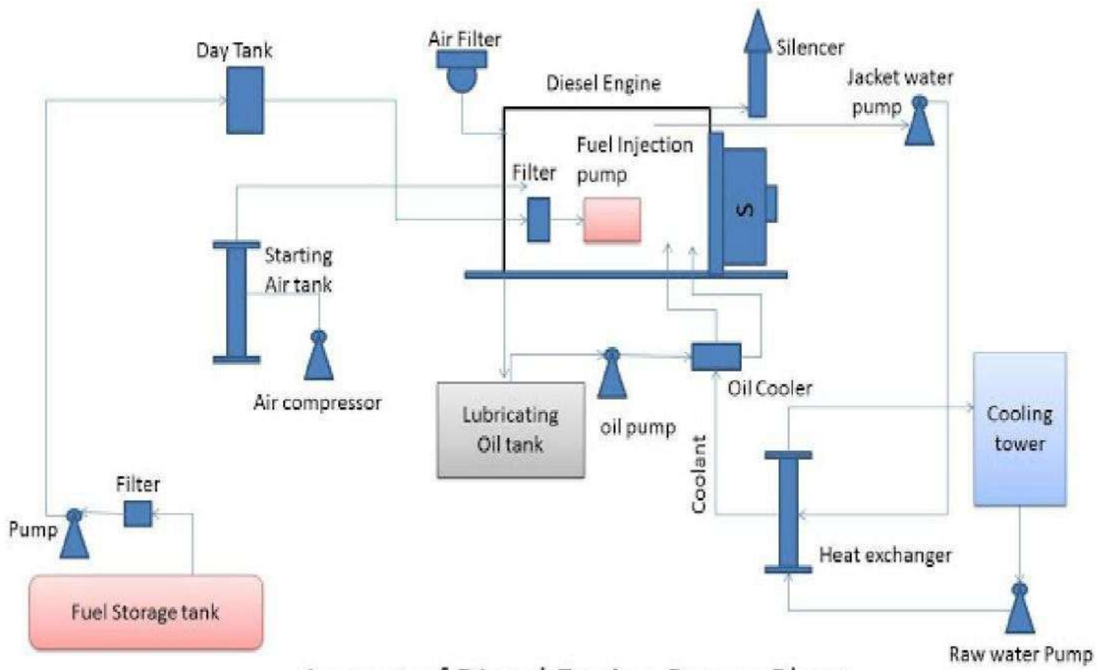
They can be used as stand-by plants to hydro-electric power plants and steam power plants for emergency services.

They can be used as peak load plants in combinations with thermal or hydro-plants.

They are quite suitable for mobile power generation and are widely used in transportation systems such as automobiles, railways, air planes and ships.

Now-a-days power cut has become a regular feature for industries. The only solution to tide over this difficulty is to install diesel generating sets.

Layout diesel engine power plant:



Layout of Diesel Engine Power Plant

Diesel engine:

Diesel engines or compression ignition engines as they are called are generally classified as two stroke engine and four stroke engines. In diesel engine, air admitted into the cylinder is compressed, the compression ratio being 12 to 20. At the end of compression stroke, fuel is injected. It burns and the burning gases expand and do work on the position. The engine is directly coupled to the generator. The gases are then exhausted from the cylinder to atmosphere.

Engine starting system:

This includes air compressor and starting air tank. The function of this system is to start the engine from cold supplying compressed air.

Fuel system:

Pump draws diesel from storage tank and supplies it to the small day tank through the filter. Day tank supplies the daily fuel need of engine. The day tan is usually placed high so that diesel flows to engine under gravity. Diesel is again filtered before being injected into the engine by the fuel injection pump. The fuel is supplied to the engine according to the load on the plant.

Air intake system:

Air filters are used to remove dust from the incoming air. Air filters may be dry type, which is made up of felt, wool or cloth. In oil bath type filters, the sir is swept over a bath of oil so that dust particles get coated.

Exhaust system:

In the exhaust system, silencer (muffler) is providing to reduce the noise.

Engine cooling system:

The temperature of burning gases in the engine cylinder is the order of 1500 to 2000'C. to keep the temperature at the reasonable level, water is circulated inside the engine in water jackets which are passage around the cylinder, piston, combustion chamber etc. hot water leaving the jacket is sent to heat exchanger. Raw water is made to flow through the heat exchanger, where it takes up the heat of jacket water. It is then cooled in the cooling tower and recirculates again.

Engine lubrication system:

It includes lubricating oil tank, oil pump and cooler. Lubrication is essential to reduce friction and wear of engine parts such as cylinder walls and piston. Lubricating oil which gets heated due to friction of moving parts is cooled before recirculation. The cooling water used in the engine is used for cooling the lubricant also.

Advantages of diesel power plant:

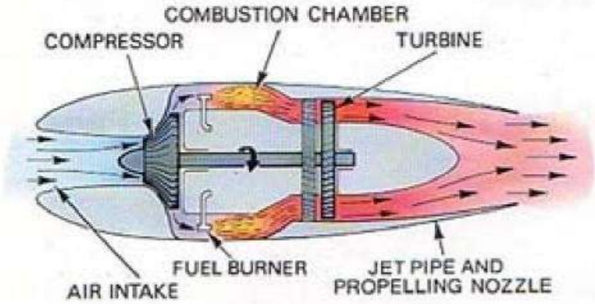
Plant layout is simple. Hence it can be quickly installed and commissioned, while the erection and starting of a steam power plant or hydro-plant takes a fairly long time.
Quick starting and easy pick-up of loads are possible in a very short time. Location of the plant is near the load center.
The load operation is easy and requires minimum labors.
Efficiency at part loads does not fall so much as that of a steam plant.
Fuel handling is easier and no problem of ash disposal exists.
The plant is smaller in size than steam power plant for same capacity. Diesel plants operate at high overall efficiency than steam.

Disadvantages of diesel power plant:

Plant capacity is limited to about 50 MW of power.
Diesel fuel is much more expensive than coal.
The maintenance and lubrication costs are high.
Diesel engines are not guaranteed for operation under continuous, while steam can work under 25% of overload continuously.

Gas Turbine Power Plant:

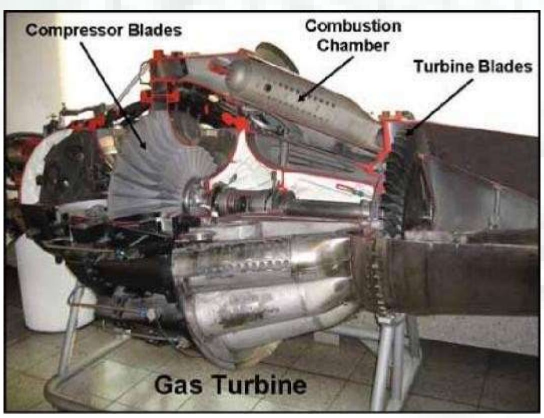
Gas turbine engines derive their power from burning fuel in a combustion chamber and using the fast flowing combustion gases to drive a turbine in much the same way as the high pressure steam drives a steam turbine.



One major difference however is that the gas turbine has a second turbine acting as an air compressor mounted on the same shaft. The air turbine (compressor) draws in air, compresses it and feeds it at high pressure into the combustion chamber increasing the intensity of the burning flame.

It is a positive feedback mechanism. As the gas turbine speeds up, it also causes the compressor to speed up forcing more air through the combustion chamber which in turn increases the burn rate of the fuel sending more high pressure hot gases into the gas turbine increasing its speed even more. Uncontrolled runaway is prevented by controls on the fuel supply line which limit the amount of fuel fed to the turbine thus limiting its speed.

The thermodynamic process used by the gas turbine is known as the Brayton cycle. Analogous to the Carnot cycle in which the efficiency is maximized by increasing the temperature difference of the working fluid between the input and output of the machine, the Brayton cycle efficiency is maximized by increasing the pressure difference across the machine. The gas turbine is comprised of three main components: a compressor, a combustor, and a turbine. The working fluid, air, is compressed in the compressor (adiabatic compression - no heat gain or loss), then mixed with fuel and burned by the combustor under constant pressure conditions in the combustion chamber (constant pressure heat addition). The resulting hot gas expands through the turbine to perform work (adiabatic expansion). Much of the power produced in the turbine is used to run the compressor and the rest is available to run auxiliary equipment and do useful work. The system is an open system because the air is not reused so that the fourth step in the cycle, cooling the working fluid, is omitted.



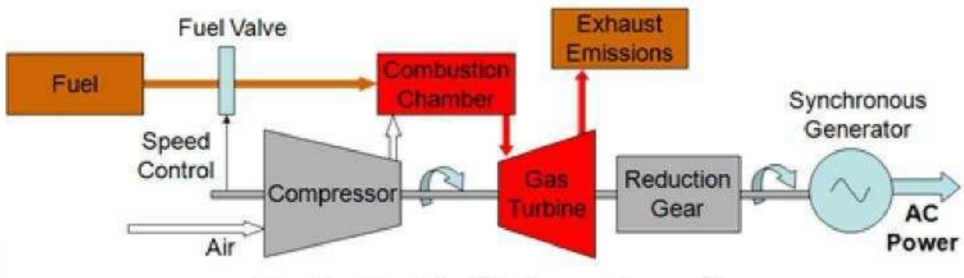
Gas Turbine Aero Engine

Gas turbines have a very high power to weight ratio and are lighter and smaller than internal combustion engines of the same power. Though they are mechanically simpler than reciprocating engines, their characteristics of high speed and high temperature operation require high precision components and exotic materials making them more expensive to manufacture.

Turbine Configurations

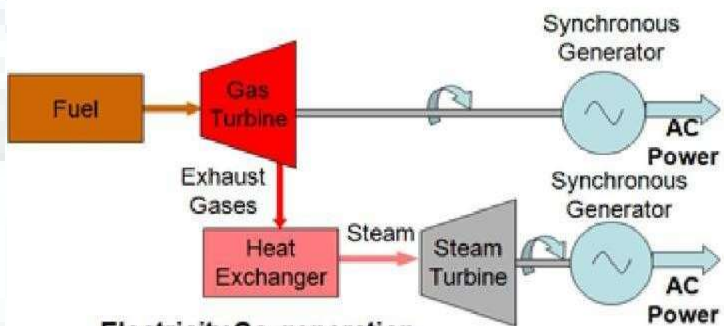
Gas turbine power generators are used in two basic configurations

Simple Systems consisting of the gas turbine driving an electrical power generator.



Gas Turbine Electric Power Generation

Combined Cycle Systems which are designed for maximum efficiency in which the hot exhaust gases from the gas turbine are used to raise steam to power a steam turbine with both turbines being connected to electricity generators.



Electricity Co-generation

<u>**Applications**</u>

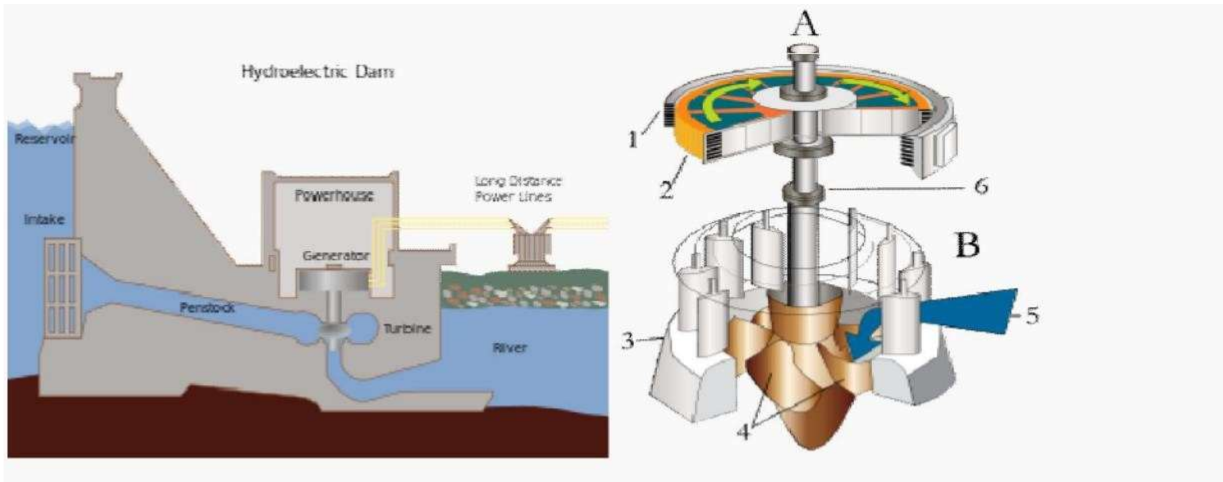
Gas turbines can be used for large scale power generation. Examples are applications delivering 600 MW or more from a 400 MW gas turbine coupled to a 200 MW steam turbine in a co-generating installation. Such installations are not normally used for base load electricity generation, but for bringing power to remote sites such as oil and gas fields. They do however find use in the major electricity grids in peak shaving applications to provide emergency peak power.

Low power gas turbine generating sets with capacities up to 5 MW can be accommodated in transportation containers to provide mobile emergency electricity supplies which can delivered by truck to the point of need.

Hydel Power Plant:

Hydroelectricity is the term referring to electricity generated by hydropower; the production of electrical power through the use of the gravitational force of falling or flowing water. It is the most widely used form of renewable energy.

Generating methods



Conventional (dams)

Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator. The power extracted from the water depends on the volume and on the difference in height between the source and the water's outflow. This height difference is called the head. The amount of potential energy in water is proportional to the head. A large pipe (the "penstock") delivers water to the turbine.

Pumped-storage

This method produces electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low electrical demand, the excess generation capacity is used to pump water into the higher reservoir. When the demand is becomes greater, water is released back into the lower reservoir through a turbine. Pumped-storage schemes currently provide the most commercially important means of large-scale grid energy storage and improve the daily capacity factor of the generation system. Pumped storage is not an energy source, and appears as a negative number in listings.

Run of the river

Run of the river hydroelectric stations are those with small or no reservoir capacity, so that the water coming from upstream must be used for generation at that moment, or must be allowed to bypass the dam. In the United States, run of the river hydropower could potentially provide 60,000 MW (about 13.7% of total use in 2011 if continuously available).

Tide

A tidal power station makes use of the daily rise and fall of ocean water due to tides; such sources are highly predictable, and if conditions permit construction of reservoirs, can also be dispatchable to generate power during high demand periods. Less common types of hydro schemes use water's kinetic energy or undammed sources such as undershot waterwheels. Tidal power is viable in a relatively small number of locations around the world. In Great Britain, there are eight sites that could be developed, which have the potential to generate 20% of the electricity used in 2012.

Advantages

Flexibility

Low power costs

Suitability for industrial applications

Reduced CO_2 emissions

Disadvantages

Ecosystem damage and loss of land

Siltation and flow shortage

Methane emissions (from reservoirs)

Relocation

Failure risks

Wind Mill:-

Wind power is extracted from air flow using wind turbines or sails to produce mechanical or electrical power. Windmills are used for their mechanical power, wind pumps for water pumping, and sails to propel ships. Wind energy as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land. The effects on the environment are generally less problematic than those from other power sources. Large wind farms consist of thousands of individual wind turbines which are connected to the transmission network. According to the recent EU analysis for new constructions, onshore wind is an inexpensive source of electricity, competitive with or in many places cheaper than coal, gas or fossil fuel plants. Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electricity to isolated off-grid locations.

Wind power is very consistent from year to year but has significant variation over shorter time scales. It is therefore used in conjunction with other sources to give a reliable supply. As the proportion of wind power in a region increases, a need to upgrade the grid, and a lowered ability to supplant conventional production can occur. Power management techniques such as having excess capacity, geographically distributed turbines, dispatch able backing sources, sufficient hydroelectric power, exporting and importing power to neighboring areas, or reducing demand when wind production is low, can in many cases overcome these problems. In addition, weather forecasting permits the electricity network to be readied for the predictable variations in production that occur.

Tide Power Plant:-

Tidal power, also called tidal energy, is a form of hydropower that converts the energy of tides into useful forms of power, mainly electricity. Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than energy and solar power. Among sources of renewable energy, tidal power has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability.

Tidal power is taken from the Earth's oceanic tides; tidal forces are periodic variations in gravitational attraction exerted by celestial bodies. These forces create corresponding motions or currents in the world's oceans. Due to the strong attraction to the oceans, a bulge in the water level is created, causing a temporary increase in sea level. When the sea level is raised, water from the middle of the ocean is forced to move toward the shorelines, creating a

tide. This occurrence takes place in an unfailing manner, due to the consistent pattern of the moon's orbit around the earth. The magnitude and character of this motion reflects the changing positions of the Moon and Sun relative to the Earth, the effects of Earth's rotation,

and local geography of the sea floor and coastlines. A tidal generator converts the energy of tidal flows into electricity. Greater tidal variation and higher tidal current velocities can dramatically increase the potential of a site for tidal electricity generation.

Geothermal Power Plant:-

Geothermal electricity is electricity generated from geothermal energy. The earth's heat content is about 10^{31} joules. This heat naturally flows to the surface by conduction at a rate of 44.2 terawatts (TW)[and is replenished by radioactive decay at a rate of 30 TW. These power rates are more than double humanity's current energy consumption from primary sources. Electricity generation requires high temperature resources that can only come from deep underground. The heat must be carried to the surface by fluid circulation, either through magma conduits, hot springs, hydrothermal circulation, oil wells, drilled water wells, or a combination of these. This circulation sometimes exists naturally where the crust is thin: magma conduits bring heat close to the surface, and hot springs bring the heat to the surface.

In ground that is hot but dry, or where water pressure is inadequate, injected fluid can stimulate production. Developers bore two holes into a candidate site, and fracture the rock between them with explosives or high pressure water. Then they pump water or liquefied carbon dioxide down one borehole, and it comes up the other borehole as a gas. Heat from a fuel source (in geothermal case, the earth's core) is used to heat water or another working fluid. The working fluid is then used to turn a turbine of a generator, thereby producing electricity. The fluid is then cooled and returned to the heat source.

Direct Energy Conversion System:

Transformation of one type of energy (such as sunlight) to another (such as electricity) without passing through an intermediate stage (such as steam to spin generator turbines). Energy transformation or energy conversion is the process of changing one form of energy to another. In physics, the term energy describes the capacity to produce certain changes within a system, without regard to limitations in transformation imposed. Changes in total energy of systems can only be accomplished by adding or removing energy from them, as energy is a quantity which is conserved (unchanging), as stated by the first law of thermodynamics. Mass-energy equivalence, which arose from special relativity, says that changes in the energy of systems will also coincide with changes (often small in practice) in the system's mass, and the mass of a system is a measure of its energy content. Energy in many of its forms may be used in natural processes, or to provide some service to society such as heating, refrigeration, light, or performing mechanical work to operate machines. For example, an internal combustion engine converts the potential chemical energy in gasoline and oxygen into thermal energy which, by causing pressure and performing work on the pistons, is transformed into the mechanical energy that accelerates the vehicle (increasing its kinetic energy). A solar cell converts the radiant energy of sunlight into energy that can then be used to light a bulb or power a computer.

CHAPTER - 2.0

THERMAL POWER STATIONS

Introduction

Much of the electricity used worldwide is produced in steam power plants. Despite efforts to develop alternative energy converters, electricity from steam will continue, for many years, to provide the power that energizes the United States and world economies. Therefore the study of energy conversion systems with this important element of industrial society is of much importance. Steam cycles used in electrical power plants and in the production of shaft power in industry are based on the familiar Rankine cycle, studied briefly in most courses in thermodynamics. In this chapter we review the basic Rankine cycle and examine modifications of the cycle that make modern power plants efficient and reliable.

A Simple Rankine-Cycle Power Plant

The most prominent physical feature of a modern steam power plant (other than its smokestack) is the steam generator, or boiler. There the combustion, in air, of a fossil fuel such as oil, natural gas, or coal produces hot combustion gases that transfer heat to water passing through tubes in the steam generator. The heat transfer to the incoming water (feedwater) first increases its temperature until it becomes a saturated liquid, then evaporates it to form saturated vapor, and usually then further raises its temperature to create superheated steam. Steam power plants operate on sophisticated variants of the Rankine cycle. These are considered later. First, let us examine the simple Rankine cycle from which the cycles of large steam power plants are derived. In the simple Rankine cycle, steam flows to a turbine, where part of its energy is converted to mechanical energy that is transmitted by rotating shaft to drive an electrical generator. The reduced-energy steam flowing out of the turbine condenses to liquid water in the condenser. A feedwater pump returns the condensed liquid (condensate) to the steam generator. The heat rejected from the steam entering the condenser is transferred to a separate cooling water loop that in turn delivers the rejected energy to a neighbouring lake or river or to the atmosphere.

Rankine cycle

Principle

This experiment is designed to acquire experience on the operation of a functional steam turbine power plant. A comparison of a real world operating characteristics to that of the ideal Rankine power cycle will be made.

Objective

The objective of this lab is to acquire experience on the basic Rankine cycle and to understand the factors and parameters affecting the efficiency and cost of generating energy. In this lab, we will determine:

- **a)** Mass Flow Rate of a Rankine Cycle.
- **b)** Thermodynamics properties (entropies, enthalpies, quality, etc). Draw a schematic of the cycle in a T-S diagram.
- **c)** Work and heat transfer in the different stages of the cycle.
- **d)** Thermal efficiency of the cycle.

e) Mass flow rate in the turbine.
f) Boiler efficiency
g) Air-Fuel ratio and air excess.
h) Cost of generating steam and energy.

Background

The Rankine cycle is the most common of all power generation cycles and is diagrammatically depicted via Figures 1 and 2. The Rankine cycle was devised to make use of the characteristics of water as the working fluid. The cycle begins in a boiler (State 4 in figure 1), where the water is heated until it reaches saturation- in a constant- pressure process. Once saturation is reached, further heat transfer takes place at a constant temperature, until the working fluid reaches a quality of 100% (State 1). At this point, the high- quality vapor is expanded isoentropically through an axially bladed turbine stage to produce shaft work. The steam then exits the turbine at State 2.

The working fluid, at State 2, is at a low- pressure, but has a fairly high quality, so it is routed through a condenser, where the steam is condensed into liquid (State 3). Finally, the cycle is completed via the return of the liquid to the boiler, which is normally accomplished by a mechanical pump. Figure 2 shows a schematic of a power plant under a Rankine cycle.

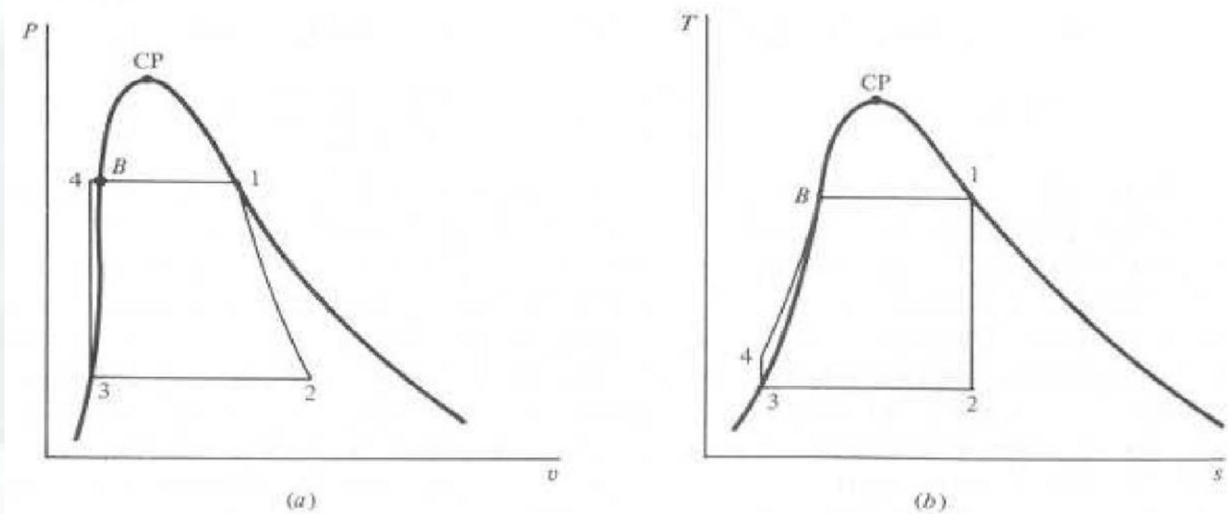


Figure 1: Diagrams for a simple ideal Rankine cycle: a) P-V diagram, b) T-S diagram

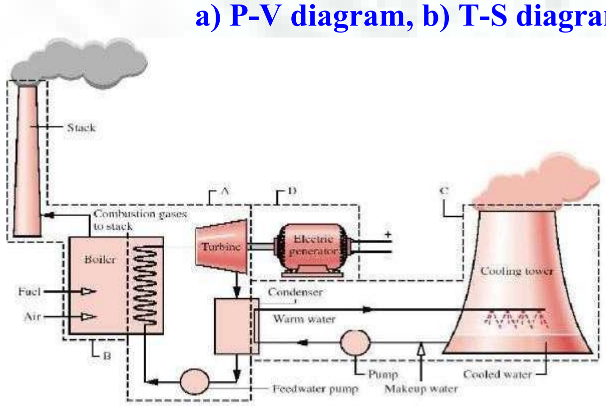


Figure 2: Schematic of a simple ideal Rankine cycle

Rankine cycle analysis

This experiment has an important difference with the cycle shown in Figure 2. The difference is that there is not a pump to complete the cycle. This is not exactly a cycle. Instead, it is an open system. The water crossing the condenser is stored in a tank as show in Figure 3, but the principle of Rankine cycle studied in Thermodynamic is still valid.

The boiler will be filled with water before the experiment and the experiment will be ended when the water is reaches the minimum level of correct operation, given by the manufacturer.

Another important difference is that between the boiler and turbine there is a valve that generates a throttling effect. The throttling process is analyzed as an isenthalpic process. This phenomenon will be analyzed more in detail. Also, the boiler generates a superheated vapor.

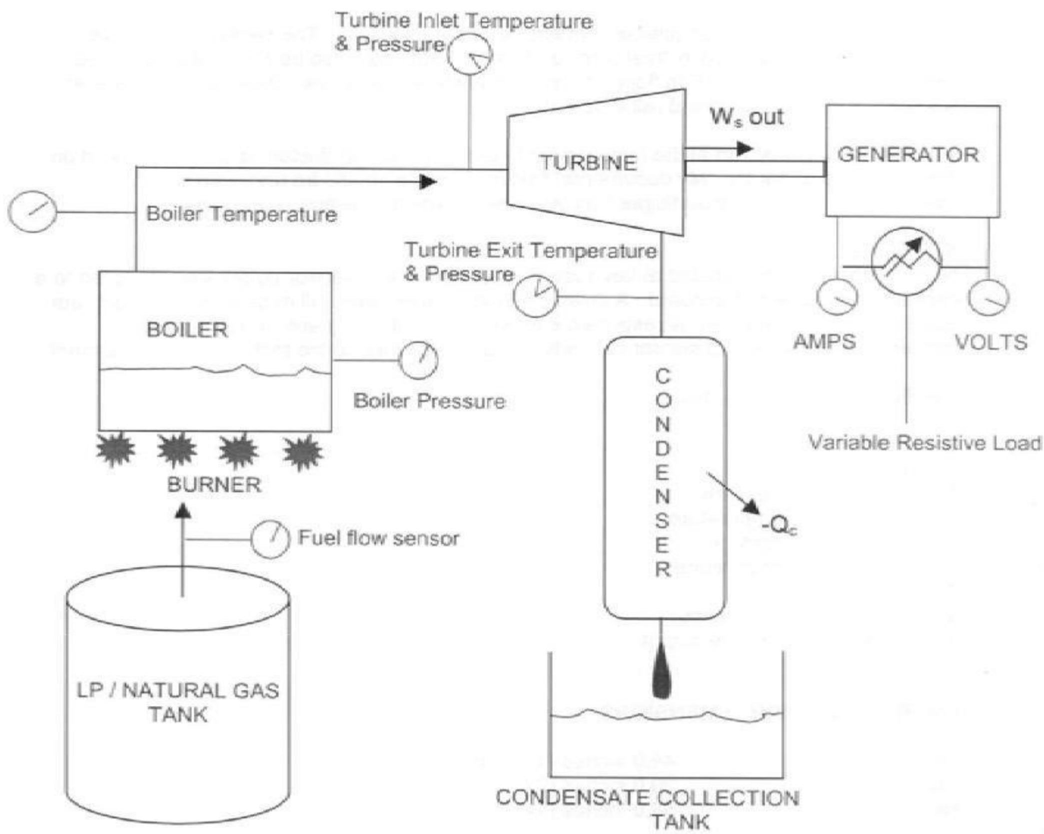
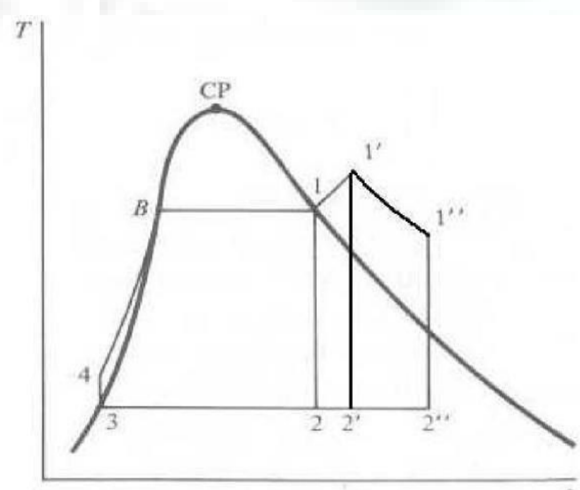


Figure 3: Schematic of Rankine cycle steam turbine apparatus



I. Mass Flow Rate of the Rankine Cycle.

Evaluating the time of operation and volume of consumed water, the mass flow rate can be measured as:

$$m_{water} \quad q_{water} \quad water \quad \frac{water}{time} \quad water$$

Here, *time* is measured with a chronometer for a known volume of water $_{water}$ in the boiler.

Work and Heat Transfer

For this analysis, it is assumed that the process is ideal and there are not pressure losses occurring in the piping, but as has been said previously the boiler generates superheated vapor and there is a throttling process in the valve. Figure 4 shows the modified cycle of the plant.

The evaporator, in this case a fire-tube boiler, produces a superheated vapor (Stage1). Taking a control volume enclosing the boiler tubes and drums, the energy rate balance gives:

$$0 \; Q \quad m \quad water \quad h \; h_4 \quad \frac{V_1^2 \; V_2^2}{2} \quad g \, z \quad 1 \, z \quad 2$$

neglecting kinetic and potential energy, the energy equation reduce to:

$$Q_{in} \quad m_{water} \quad h_1 \quad h_4$$

Then, vapors pass through the valve, states1'-1". For a control volume enclosing the valve, the mass and energy rate balance reduces under steady state to:

$$0 \quad v \quad water \quad 1 \quad 1 \qquad Q \quad m \quad h \quad h$$

Since there is not work done in the valve and heat transfer Q_v can be neglected, last equation reduces to:

$$h_1 \quad h_1$$

which means that there is an isenthalpic expansion in the valve.

Making a similar analysis for the pump and condenser, the work and heat transfer are:

$$Q_{out} \quad m_{water} \quad h_2 \quad h_3 \quad \text{and} \quad W_p \quad m_{water} \; h_4 \quad h_3$$

The energy balance for a control volume around the turbine under steady state condition is:

$$0 \quad Q_{cv} \quad W_t \quad m_{water} \; h_1 \quad h_2$$

Neglecting heat transfer Q_{cv} to the surrounding, the process in the turbine is assumed adiabatic and reversible, so isentropic (S_2 S_1) and the energy equation reduces to:

$$W_t \quad m_{water} \quad h \quad h_2$$

Then, knowing that S_2 S_1 and also S_{f2} and S_{g2} which could be estimated with the pressure and temperature at outlet of the turbine, the quality of the vapor can be calculated as:

$$x_2 \quad \frac{S_{g2} \quad S_1}{S_{g2} \quad S_{f2}}$$

with x_2 , the enthalpy h_2 is calculated as:

$$h_2 \quad h_{g2} \quad x_2 \quad h_{g2} \quad h_{f2}$$

where h_{f2} and h_{g2} are calculated with the outlet temperature. It is important to emphasize that the valve generates entropy from state 1 to the state1 . Without the expansion valve the cycle would be close to an isentropic expansion 2 in the turbine. All parameters h_1, h_1, S_1, S, S, h and S 1 1 B 4 can be determined from temperatures and pressures at each stage.

Thermal Efficiency of Cycle

The net work of the cycle is defined by the difference between the turbine work and the pump work:

$$W_{cycle}\ W_t\quad W_p\quad m_{water}\ h_1\ h_2\quad m_{water}\ h_4\ h_3$$

If the pump work is neglected, the net work of the cycle reduces to:

$$W_{cycle}\quad m_{water}\ h_1\ h_2$$

Then the thermal efficiency of this system is defined by the rate between the net work and heat transfer from the boiler:

$$\frac{W_t}{Q_{in}}\quad \frac{h_1\ h_2}{h_1\ h_4}$$

II. Air -Fuel ratio and Air Excess.

The chemical composition of the gases at the outlet of boiler is:

$$A\ CO_2\quad B\ CO\quad C\ NO\quad D\ O_2\quad F\ NO_2\quad G\ N_2\quad M_{water}\ H_2O$$

at the inlet, there are dry air and fuel (butane):

$$M_{air}\ O_2\ 3.76\ N_2\ M_{fuel}\ C_4H_{10}$$

Then, making a balance between inlet and outlet:

$$M_{air}\ O_2\quad 3.76N_2\quad M_{fuel}\ C_4H_{10}\quad A\ CO_2\quad B\ CO\quad C\ NO\quad D\ O_2\quad F\ NO_2\quad G\ N_2\quad M_{water}\ H_2O$$

so,

$$M_{fuel}\quad \frac{A\quad B}{4}$$

$$M_{air}\quad \frac{C\quad F\quad 2G}{3.76}$$

$$M_{water}\quad \frac{M_{fuel}}{5}$$

Where the coefficients (*A, B, C, D, F, G and M_i*) are the molar mass necessary to balance the equation. Then the air excess is:

$$E_{air}\quad \frac{M_{air}}{(M_{air})\ ideal}\ 100$$

the M_{air} (*ideal*) is the molar mass of air when the chemical reaction is complete, and there is not formation of water and intermediate compounds:

$$M_{air}(ideal)\ O_2\ 3.76N_2\quad C_4H_{10}\quad A\ CO_2\quad G\ N_2\quad M_{water}\ H_2O$$

Balancing this equation: $(M_{air})_{ideal}\ 13/2$, $G\ 24.44$, A 4 and M_{water} 5 , which is:

$$\frac{13}{2}O_2\quad 3.76N_2\quad C_4H_{10}\quad 4\ CO_2\quad 24.44\ N_2\quad 5\ H_2O$$

Then, the Air-Fuel ratio is defined by:

$$AF_M \quad \frac{M_{air} \, P_{air}}{fuel \quad fuel} \quad P$$

Where P_{air} and P_{fuel} are the atomic weight of air and combustible, respectively. The P_{air} 29 *kg/Kmol* and the P_{fuel} $4P_c$ $10P_H$ 58.12 *kg/Kmol*.

III. Mass flow rate in the turbine

From the generated amperage and voltage:

$$W_t \quad VI$$

so, the mass flow rate in the turbine is:

$$m \quad \frac{VI}{_t \, h_1 \quad h_2}$$

Where $_t$ is the efficiency of the turbine. Here, we will assume this efficiency equal to one.

IV. Boiler analysis

From the chemical equation of combustion, balanced in term of moles:

$$mass_{air} \, O_2 \, 3.76N_2 \quad mass_{comb} \, C_4H_{10} \, A \, CO_2 \quad B \, CO \quad C \, NO \quad D \, O_2 \quad F \, NO_2 \quad GN_2 \quad MH_2O$$

the first law of thermodynamics for a volume enclosing the boiler is:

$$mh_R \quad Q_{comb} mh_P$$

where and are the sum for each reactants and products of combustion. Remember $_R$ $_P$

that m_i n_i M_i m_i , iswheremass, n_i is number of moles and M_i is the molar mass of the *i-th* component. Last equation is written in the form:

$$nMh_R \quad Q_{comb} nMh_P$$

Enthalpy of formation: -

Another form to write the first law is:

$$nM \, h^0_f \quad h_R \quad Q_{comb} nM \, h^0_f \quad h_P$$

where h^0 is the enthalpy of reactants and products, respectively, at the standard temperature and pressure. f

$$Q_{comb} \quad nM \, h^0_f \quad h_P \quad nM \, h^0_f \quad h_R$$

$$nM \, h_{0f}{}_P \, nM \, h_{0f}{}_R \, nM \quad h_P \, nM \quad h_R$$

The first two terms are the enthalpy of combustion ($\bar{h}_{PR}{}^0$) at standard temperature and pressure.

$$Q_{comb} \quad \bar{h}_{PR}{}^0 \quad nM \quad h_P \quad nM \quad h_R$$

Enthalpy of formation, HHV and LHV: -

The enthalpy of combustion also is called *heating value* (HV), and this is number indicative to the useful energy content of different fuels. There are two types of heating value: *higher heating value* (HHV) and the lo*wer heating value* (LHV). The HHV is obtained when all the water formed by combustion is a liquid. The LHV is obtained when all the water formed by the combustion is a vapor. For that HHV is more than LHV (see Table 1). For calculations, we will assume that water formed is in the liquid state and the HHV will be used for h_{PR}^{0} . Now, we can calculate the efficiency of the boiler as:

$$_{boiler} \quad \frac{Q_{in}}{Q_{comb}}$$

V. Cost of Generating Steam and Energy.

The mass flow of fuel is the product between the density and fuel flow mass and the time of operation:

$$m_{fuel} \quad _{fuel} \; q_{fuel}$$

where $_{fuel}$ is the density of butane gas at atmospheric pressure. Then the cost of generating steam per unit mass of steam is:

$$STEAM\ cost \; \frac{m_{fuel} \; Price_{fuel}}{m_{water}}$$

where $Price_{fuel}$ is the price of the fuel. Also it is possible to determine the cost of generating energy by:

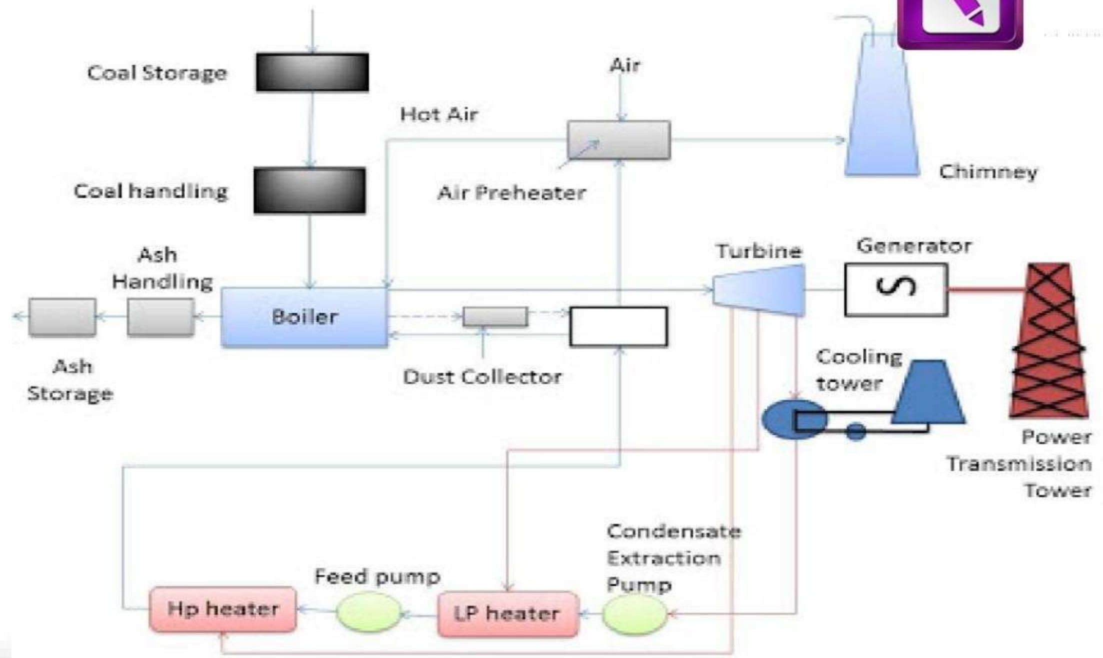
$$ENERGY\ cost \; \frac{m_{fuel} \; Price_{fuel}}{VI}$$

A steam power plant, also known as thermal power plant, is using steam as working fluid. Steam is produced in a boiler using coal as fuel and is used to drive the prime mover, namely, the steam turbine. In the steam turbine, heat energy is converted into mechanical energy which is used for generating electric power. Generator is an electro-magnetic device which makes the power available in the form of electrical energy.

Layout of steam power plant:

The layout of the steam power plant is shown in figure below. It consists of four main circuits. These are:

Coal and ash circuit.
Air and flue gas circuit
Water and steam circuit
and Cooling water circuit



Coal and ash circuit:

Coal from the storage yard is transferred to the boiler furnace by means of coal handling equipment like belt conveyor, bucket elevator, etc., ash resulting from the combustion of coal in the boiler furnace collects at the back of the boiler and is removed to the ash storage yard through the ash handling equipment.

Ash disposal :

The indian coal contains 30% to 40% ash. A power plant of 100MW 20 to 25 tonnes of hot ash per hour. Hence sufficient space near the power plant is essential to dispose such large quantities of ash.

Air and flue gas circuit:

Air is taken from the atmosphere to the air preheater. Air is heated in the air preheater by the heat of flue gas which is passing to the chimney. The hot air is supplied to the furnace of the boiler.

The flue gases after combustion in the furnace, pass around the boiler tubes. The flue gases then passes through a dust collector, economizer and pre-heater before being exhausted to the atmosphere through the chimney. By this method the heat of the flue gases which would have been wasted otherwise is used effectively. Thus the overall efficiency of the plant is improved.

Air pollution:

The pollution of the surrounding atmosphere is caused by the emission of objectable gases and dust through the chimney. The air pollution and smoke cause nuisance to people surrounding the planet.

Feed water and steam circuit:

The steam generated in the boiler passes through super heater and is supplied to the steam turbine. Work is done by the expansion of steam in the turbine and the pressure of steam is reduced. The expanded steam then passes to the condenser, where it is condensed.

The condensate leaving the condenser is first heated in a l.p. water heater by using the steam taken from the low pressure extraction point of the turbine. Again steam taken from the high pressure extraction point of the turbine is used for heating the feed water in the H.P water heater. The hot feed water is passing through the economizer, where it is further heated by means of flue gases. The feed water which is sufficiently heated by the feed water heaters and economizer is then fed into the boiler.

Cooling water circuit:

Abundant quantity of water is required for condensing the steam in the condenser. Water circulating through the condenser may be taken from various sources such as river or lake, provided adequate water supply is available from the river or lake throughout the year.
If adequate quantity of water is not available at the plant site, the hot water from the condenser is cooled in the cooling tower or cooling ponds and circulated again.

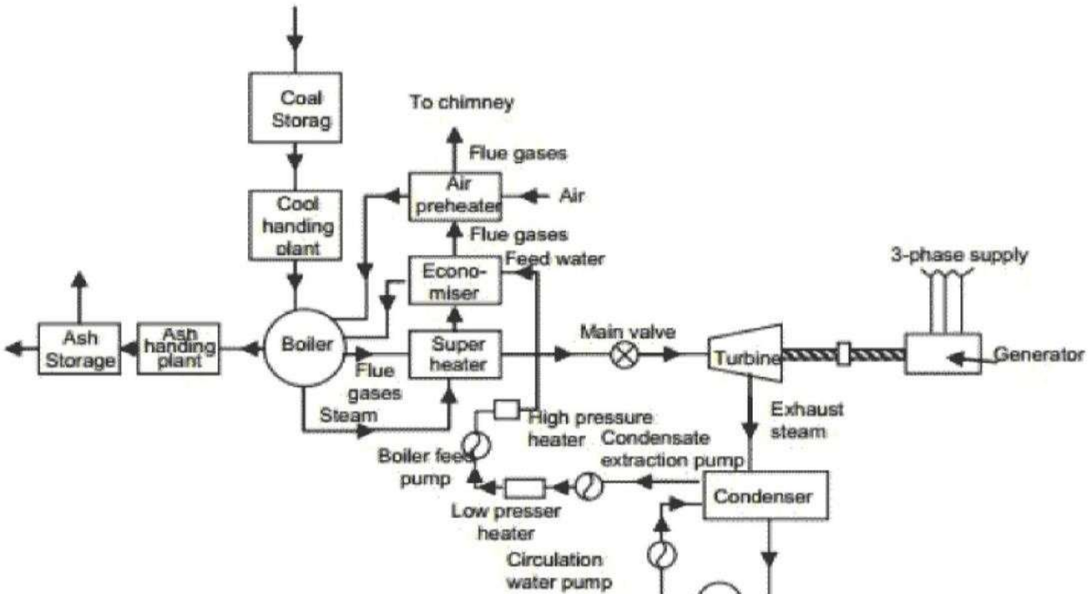
Advantages of thermal power plants

1. Initial cost is low compared with hydro-plant.
2. The power plant can be located near load center, so the transmission losses are considerably reduced.
3. The generation of power is not dependent on the nature's mercy like hydro plant.
4. The construction and commissioning of thermal plant requires less period of time than a hydro plant.

Economizer:

An economiser is a mechanical device which is used as a heat exchanger by preheating a fluid to reduce energy consumption. In a steam boiler, it is a heat ex-changer device that heats up fluids or recovers residual heat from the combustion product i.e. flue gases in thermal power plant before being released through the chimney. Flue gases are the combustion exhaust gases produced at power plants consist of mostly nitrogen, carbon dioxide, water vapor, soot carbon monoxide etc. Hence, the **economizer in thermal power plants**, is used to economise the process of electrical power generation, as the name of the device is suggestive of. The recovered heat is in turn used to preheat the boiler feed water, that will eventually be converted to super-heated steam. Thus, saving on fuel consumption and economizing the process to a large extent, as we are essentially gathering the waste heat and applying it to, where it is required. Nowadays however, in addition to that, the heat available in the exhaust flue gases can be economically recovered using air pre-heater which are essential in all pulverized coal fired boiler.

Working Principle of Economizer



As shown in the figure above, the flue gases coming out of the steam boiler furnace carry a lot of heat. Function of economiser in thermal power plant is to recover some of the heat from the heat carried away in the flue gases up the chimney and utilize for heating the feed water to the boiler. It is simply a heat ex-changer with hot flue gas on shell side and water on tube side with extended heating surface like Fins or Gills. **Economisers in thermal power plant** must be sized for the volume and temperature of flue gas, the maximum pressure drop passed the stack, what kind of fuel is used in the boiler and how much energy needs to be recovered.

When the water is boiled in steam boiler, the steam is produced which is then super-heated after which it is passed to the turbines. Then the exhausted steam from turbine blades, is passed through steam condenser of turbine in which the steam is condensed and this condensed water then is pre warmed first in feed water heater then in it before re-feeding in boiler.

It is placed in the passage of flue gases in between the exit from the boiler and the entry to the chimney. In this a large number of small diameter thin walled tubes are placed between two headers. The flue gases flow outside the tubes usually in counter flow.

Process of Heat Transfer in Economizer, Evaporator and Superheater

Heat transfer to water in steam generator takes place in 3 different regimes, as shown in the figure below. Water is at first pre-heated sensibly in the **economizer** in liquid phase at a certain pressure from state 4 to state 5 (refer to the diagram below) till it becomes a saturated liquid.

It is then send to the evaporator, where this saturated liquid is boiled associating a change of phase from 5 to 6 by absorbing the latent heat of vaporization, at that particular pressure. Now this saturated vapor in state 6 is further heated in the super-heater, to bring it to state 1, i.e. in gaseous or vapor form. For unit mass of fluid, the heat transfer equation in the 3 types of heat ex-changers are given by,

$Q_{Economizer} = h_5 – h_4$

$Q_{Evaporator} = h_6 – h_5$

$Q_{Superheater} = h_1 – h_6$

Out, of these 3 major heat ex-changer components, only the economizer operates with, zero fuel consumption, and thus it is one of the most vital and economical equipment in a thermal power plant

Reheat Cycle

In simple rankine cycle, after the isentropic expansion in turbine , steam is directly fed into condenser for condensation process. (Refer this article for better understanding). But in reheat system, two turbines (high pressure turbine and low pressure turbine) are employed for improving efficiency. Steam, after expansion from high pressure turbine, is sent again to boiler and heated till it reaches superheated condition. It is then left to expand in low pressure turbine to attain condenser pressure.

As has been already mentioned in Secs. 11.1 and 11.2, if very wet steam flows through a turbine, the hydrodynamic conditions for the turbine blades and nozzles deteriorate sharply, causing a reduction of the internal relative efficiency of the turbine, $\eta_{i...r}$; this in turn leads to a reduction of the effective (thermal) efficiency of the power plant as a whole. For modern turbines the admissible dryness fraction of exhaust steam (at the turbine exit) should be not less than x = 0.86 to 0.88.

As has already been mentioned, one of the ways to reduce the wetness of exhaust steam at the turbine exit is to superheat the steam in the boiler. Superheating leads to an increase in the thermal efficiency of the cycle realized, and at the same time, on the *T-s* diagram it shifts the point corresponding to the conditions of exhaust steam to the right, into the region of greater dryness fractions, as illustrated in Fig. 11.20a.

We have also found that with the same superheat temperature the use of high pressures increases the cycle areas ratio and, consequently, the thermal efficiency of the cycle, but simultaneously a higher pressure diminishes the dryness fraction of the exhaust steam and the internal relative efficiency of the turbine.

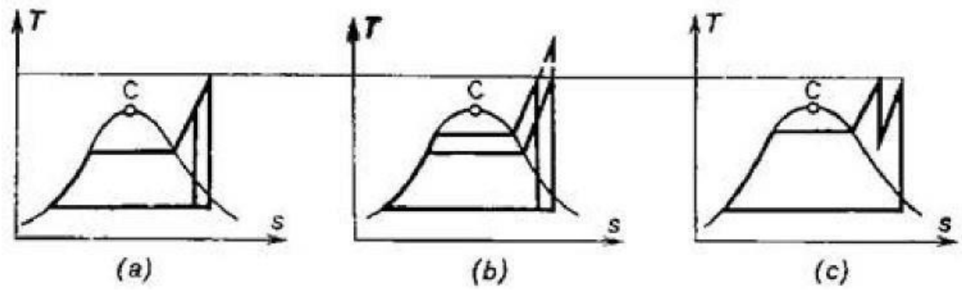


Fig. 11.20

One solution could be to further increase the superheat temperature. However, as was already mentioned, further temperature increases are restricted by the properties of construction materials. The economic advantage of this undertaking should also take into consideration increased investments involved in building such a plant.

One way to reduce the final wetness of exhaust steam is to reheat the steam. After the flow of steam, performing work in the turbine, expands to some pressure $p^* > p_2$, it is extracted from the turbine and directed to flow into an additional superheater, or reheater, installed, for instance, in the boiler flue. In this reheater, steam temperature rises to T^*, and then the steam flows back into the turbine, in which it expands to the pressure p_2. As can be seen from the *T-s* diagram, shown in Fig. 11.20c, the final wetness of steam diminishes.

The diagram of a power plant with steam reheating is shown in Fig. 11.21, in which the reheat superheater, or reheater, is designated by RS. When reheating the steam, the turbine is a two-cylinder unit, comprising a high-pressure turbine and a low-pressure turbine arranged on a common shaft along with a generator.

Figure 11.22 shows on a *T-s* diagram an internally reversible reheat cycle of the steam power plant, practising superheating. It is clear that this cycle can be visualized as consisting of two individual cycles, the conventional Rankine cycle (main) *5- 4-6-1-2-3-5* and an additional cycle *2-7- 8-9-2* (the line *7-8* is an isobar p^* = const). It can be assumed that the work done along the section *7-2* of the expansion adiabatic in the main cycle is spent to ensure adiabatic compression of the working medium on the section *2-7* of the additional cycle.

Regenerative cycle

Regenerative cooling is a method of cooling gases in which compressed gas is cooled by allowing it to expand and thereby take heat from the surroundings. The cooled expanded gas then passes through a heat exchanger where it cools the incoming compressed gas.

A **regenerative heat exchanger**, or more commonly a **regenerator**, is a type of heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid. To accomplish this hot fluid is brought into contact with the heat storage medium, then the fluid is displaced with the cold fluid, which absorbs the heat.

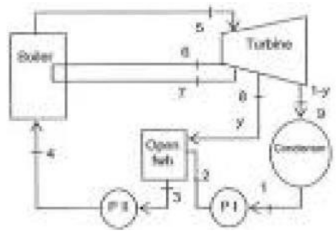
In regenerative heat exchangers, the fluid on either side of the heat exchanger can be the same fluid. The fluid may go through an external processing step, and then it is flowed back through the heat exchanger in the opposite direction for further processing. Usually the application will use this process cyclically or repetitively.

Regenerative heating was one of the most important technologies developed during the Industrial Revolution when it was used in the hot blast process on blast furnaces. It was later used in glass and steel making, to increase the efficiency of open hearth furnaces, and in high pressure boilers and chemical and other applications, where it continues to be important today.

Another type of regenerator is called a **micro scale regenerative heat exchanger**. It has a multilayer grating structure in which each layer is offset from the adjacent layer by half a cell which has an opening along both axes perpendicular to the flow axis. Each layer is a composite structure of two sub-layers, one of a high thermal conductivity material and another of a low thermal conductivity material. When a hot fluid flows through the cell, heat from the fluid is transferred to the cell wells, and stored there. When the fluid flow reverses direction, heat is transferred from the cell walls back to the fluid.

A third type of regenerator is called a "*Rothemuhle*" regenerator. This type has a fixed matrix in a disk shape, and streams of fluid are ducted through rotating hoods.

The *Rothemuhle* regenerator is used as an air preheater in some power generating plantsThe thermal design of this regenerator is the same as of other types of regenerator



Steam-generating unit

The wide diversity of parts, appurtenances, and functions needed to release and utilize a source ofheat for the practical production of steam at pressures to 5000 lb/in.^{2} (34 megapascals) andtemperatures to 1100°F (600°C), often referred to as a steam boiler for brevity. *See* **Steam**

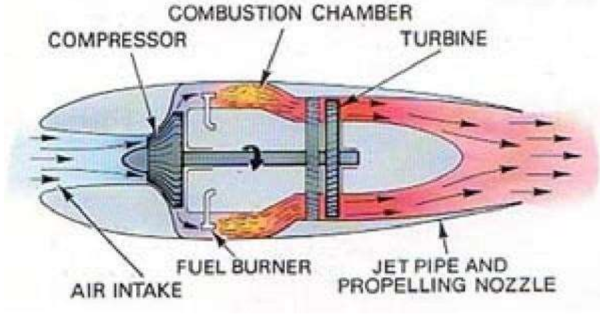
The essential steps of the steam-generating process include (1) a furnace for the combustion of fuel,or a nuclear reactor for the release of heat by fission, or a waste heat system; (2) a pressure vesselin which feedwater is raised to the boiling temperature, evaporated into steam, and generallysuperheated beyond the saturation temperature; and (3) in many modern central station units, areheat section or sections for resuperheating steam after it has been partially expanded in a turbine.This aggregation of functions requires a wide assortment of components, which may be variouslyemployed in the interests, primarily, of capacity and efficiency in the steam-production process. Theselection, design, operation, and maintenance of these components constitute a complex process.*See* Boiler, Reheating

A **boiler** or **steam generator** is a device used to create steam by applying heat energy to water. Although the definitions are somewhat flexible, it can be said that older steam generators were commonly termed *boilers* and worked at low to medium pressure (1–300 psi or 6.895–2,068.427 kPa) but, at pressures above this, it is more usual to speak of a *steam generator*.

A boiler or steam generator is used wherever a source of steam is required. The form and size depends on the application: mobile steam engines such as steam locomotives, portable engines and steam-powered road vehicles typically use a smaller boiler that forms an integral part of the vehicle; stationary steam engines, industrial installations and power stations will usually have a larger separate steam generating facility connected to the point-of-use by piping.
A notable exception is the steam-powered fireless locomotive, where separately-generated steam is

Gas Turbine Working Principle

Gas turbine engines derive their power from burning fuel in a combustion chamber and using the fast flowing combustion gases to drive a turbine in much the same way as the high pressure steam drives a steam turbine.



One major difference however is that the gas turbine has a second turbine acting asan air compressor mounted on the same shaft. The air turbine (compressor) draws in air, compresses it and feeds it at high pressure into the combustion chamber increasing the intensity of the burning flame.

It is a positive feedback mechanism. As the gas turbine speeds up, it also causes the compressor to speed up forcing more air through the combustion chamber which in turn increases the burn rate of the fuel sending more high pressure hot gases into the gas turbine increasing its speed even more. Uncontrolled runaway is prevented by controls on the fuel supply line which limit the amount of fuel fed to the turbine thus limiting its speed.

The thermodynamic process used by the gas turbine is known as the Brayton cycle. Analogous to the Carnot cycle in which the efficiency is maximised by increasing the temperature difference of the working fluid between the input and output of the machine, the Brayton cycle efficiency is maximised by increasing the pressure difference across the machine. The gas turbine is comprised of three main components: a compressor, a combustor, and a turbine. The working fluid, air, is compressed in the compressor (adiabatic compression - no heat gain or loss), then mixed with fuel and burned by the combustor under constant pressure conditions in the combustion chamber (constant pressure heat addition). The resulting hot gas expands through the turbine to perform work (adiabatic expansion). Much of the power produced in the turbine is used to run the compressor and the rest is available to run auxiliary equipment and do useful work. The system is an open system because the air is not reused so that the fourth step in the cycle, cooling the working fluid, is omitted.

Steam Prime mover

The component of a power plant that transforms energy from the thermal or the pressure form to themechanical form. Mechanical energy may be in the form of a rotating or a reciprocating shaft, or ajet for thrust or propulsion. The prime mover is frequently called an engine or turbine and isrepresented by such machines as waterwheels, hydraulic turbines, steam engines, steam turbines,windmills, gas turbines, internal combustion engines, and jet engines. These prime movers operateby either of two principles: (1) balanced expansion, positive displacement, intermittent flow ofa working fluid into and out of a piston and cylinder mechanism so that by
pressure difference onthe opposite sides of the piston, or its equivalent, there is relative motion of the machine parts; or (2)free continuous flow through a nozzle where fluid acceleration in a jet (and vane) mechanism givesrelative motion to the machine parts by impulse, reaction, or both.

Turbine A machine that transforms energy from/to thermal, electrical or pressure to/from mechanical form, typically an engine or turbine

Prime mover (locomotive), a component of a locomotive

Steam prime movers are either reciprocating engines or turbines, the former being the older, dominant type until 1900. Reciprocating engines offer low speed (100 to 400 r/min), high efficiency in small sizes (less than 500 hp), and high starting torque. In the Industrial Revolution, they powered mills and steam locomotives. Steam turbines are a product of the twentieth century and have established a wide usefulness as prime movers. They completely dominate the field of power generation and are a major prime mover for variable-speed applications in ship propulsion (through gears), centrifugal pumps, compressors, and blowers. Steam turbines are made in a variety of sizes.

Steam condensing unit

The surface condenser often used on a steam turbine, the condensing apparatus on a steam locomotive does not normally increase the power output rather it decreases. In fact it may reduce it considerably. Whilst more power is potentially available by expanding down to a vacuum, the corresponding low density (high specific volume) implies extremely bulky low pressure cylinders or a turbine would be needed to actually extract it. So with a more practical volume ratio the condenser pressure would be near atmospheric rather than at a more typical low pressure, and the temperature would be correspondingly higher. In exhausting hot steam to the condenser, the temperature gradient between the exhaust steam and the cooling water is greater, so that a smaller heat exchange surface area is needed than would be required for typical stationary or ship-based steam plant of similar power. However none of the energy in the hot steam is available to do mechanical work. Because of the relatively high temperature in a locomotive condenser, the potential improvement in thermal efficiency expected from including the condenser in the cycle is not usually realised within the space constraints of a typical locomotive. Indeed, losses due to viscous friction in the condenser piping are likely to reduce the power output .

Coal handling system

A **coal preparation plant** (CPP) is a facility that washes coal of soil and rock, crushes it into graded sized chunks (sorting), stockpiles grades preparing it for transport to market, and more often than not, also loads coal into rail cars, barges, or ships. A CPP may also be called a **coal handling and preparation plant** (CHPP), **coal handling plant**, **prep plant**, **tipple** or **wash plant**.

The more of this waste material that can be removed from coal, the lower its total ash content, the greater its market value and the lower its transportation costs achievable from simply venting to atmosphere.

The coal delivered from the mine that reports to the coal preparation plant is called run-of-mine, or ROM, coal. This is the raw material for the CPP, and consists of coal, rocks, middlings, minerals and contamination. Contamination is usually introduced by the mining process and may include machine parts, used consumables and parts of ground engaging tools. ROM coal can have a large variability of moisture and maximum particle size.
Coal needs to be stored at various stages of the preparation process, and conveyed around the CPP facilities. Coal handling is part of the larger field of bulk material handling, and is a complex and vital part of the CPP.

Advantages and Disadvantages of Reheating

Advantages of Reheating

(a) boosts up turbine efficiency

(b) eliminates an erosion-corrosion problem of turbine blades

(c) enhances the turbine output

(d) improves the steam quality

(c) increases the nozzle and blade efficiencies (f) all are correct

Disadvantages of Reheating

(a) is a cost intensive programme

(b) gain in thermal efficiency due to reheating may not justify a high initial cost

(c) requires more maintenance

(d) invites control complicacy

(e) does not beget a progressive gain in thermal efficiency in spite of addition of a number of reheating schemes

Simple problem on steam power plant.

Problem - 1 : Asteam power plant operates in the basic Rankine- cycle. It receives 4 MPa steam from the boiler faring coal to liberate heat at a steady rate of 100 MW. The steam after expansion in the turbine is exhausted to a condenser that operates at 75 kPa. The adiabatic efficiency of turbine is 85%.

Calculate

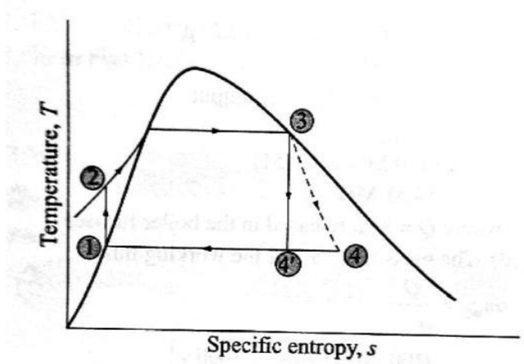
(a) cycle efficiency

(b) power output (MW) of the plant

(c) mass flow rate of the working fluid

(d) specific steam consumption

Sol: This cycle is the same as the one described except process 3--- 4. Though this process, in the present example is adiabatic, it is irreversible and hence represented by a dash line in the T-s diagram.



Actual Rankine-like cycle.

Note : The vertical line 3-4' corresponds to isentropic expansion when the turbine is reversible.

Now, w_{34} w x

911 kJ kg 1 x 0.85

77 34' STs0 4.35 kJ kg 1

STs0 represents the ideal steal turbine efficiency in which steam expands isentropically (s0)

1 2 Isentropic (adiabatic) compression

w_{12} h_1 h_2 4kJ kg 1 V_1 (P_1 P_2)

2 3 Cons tan t volumeheating

q_{23} h_3 h_2 2628 kJ kg 1

3 4 Adiabatic exapansion

w_{34} 774.35 kJ kg 1

w_{net} w_{12} w_{34} 774.35 (4)kJ kg 1) 770.35kJ kg 1

q_{input} q_{in} q_{23} 2628kJ kg 1

(a) The actual cycle efficiency

$_{actual}$ $\frac{w_{net}}{q_{in}}$ 770.35 kJ kg 1 / 2628kJ kg 1 X 100% 29.31%

Note : The efficiency ratio

$_{actual}$ / $_{ideal}$

29.31%

34.51% 0.8493

(b) The mechanical power output

W = Q $_{actual}$ = (100 MW) (29.31%) = 29.31 MW

Where Q = heat released in the boiler furnace

Note : The actual power output is less than the ideal power output (34.51 MW)

(c) The mass flow rate of the working fluid

$$m_{wf} = \frac{Q}{q_{2-3}}$$

$$= \frac{(100 \times 1000)\, kJ\, S^{-1}}{2628\, kJ\, kg^{-1}} \times \frac{3600\, s}{1h}$$

$$= 136,986\, kg\, h^{-1}$$

The mass flow rate of the working fluid remains the same as the q_{2-3} and the heat input rate remain the same in both the ideal and actual cycle.

(d) The specific steam consumption

$$SSC = \frac{m_{wf}}{W\,(kW)}$$

$$\frac{m_{wf}\,(kgh^{-1})}{W(kW)} \quad 3600\, s$$

$$= \frac{3600\, kg\, W\, h^{-1}}{w}$$

$$3600 / 770.4\, (kg\, W\, h^{-1}) = 4.6728\, kg\, k\, W\, h^{-1}$$

This value is nearly 18% higher than for the ideal case. This implies that the actual power plant must be larger in size to accommodate a higher flow rate of steam to get the same work output.

Rankine Cycle with Superheated Steam

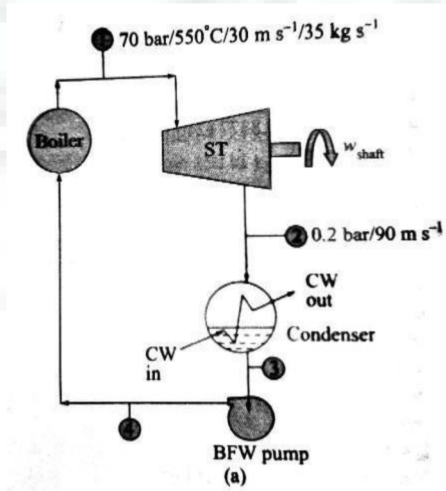
Problem - 2 : Asteam power plant operates in the basic me cycle with superheated steam. The boiler sends 35 kg s^{-1} steam (70 bar/550°C) with a velocity of 30ms^{-1}. The exhaust steam (0.2 bar, wet) is discharged to the condenser at a velocity of 90 ms^{-1}.

Determine the

(a) thermal efficiency of the cycle

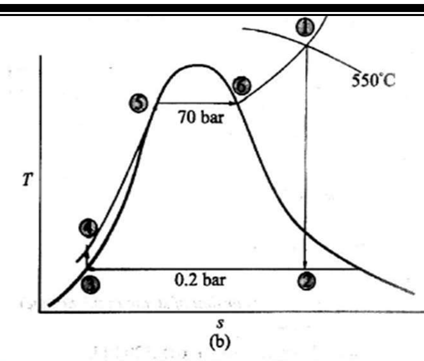
(b) net power produced

Sol :



Schematic flow diagram of the given Rankine cycle.

State1 (70bar / 55^0 0c / 30m s^{1}/ 35kg s^{1}):



Schematic T–s diagram of the given Rankine cycle.

h_1 3531 kJ kg^{1}

S_1 6.9486 kJ kg^{1} k^{1}

State 2 (0.2bar) :

S_2 S_1

(isentropic expansion of steam in the turbine)

Also,

$S_1 \quad S_2 \quad S_{f2} \quad X_2 \, S_{fg2}$

0.8319 kJ kg^{1} k^{1} X_2 (7.0766 kJ kg^{1} k^{1})

X_2 0.86435

$h_2 \quad h_{f2} \quad X_2 h_{fg2}$

251.38kJ kg^{1} 0.86435 (2358.3 kJ kg^{1})

2289.790 kJ kg^{1}

State 3 (0.2bar) :

h_3 h_{f2} 251.38kJ kg^{1}

(as the working fluid is a saturated liquid)

v_3 0.001071 m^3 kg^{1}

Turbine work,

(This can be obtained by applying the SFEE)

$h_1 \; \frac{1}{2} v_1^2 \; Z_1 \; q \; h_2 \; \frac{1}{2} v_2^2 Z_2 \; w_{shaft} \quad (q \; 0 \text{ and } Z_1 \; Z_2)$

$w_{shaft} \quad (h_1 \; h_2) \; \frac{1}{2} (v_1^2 \; v_2^2)$

$(3531 \; 2289.79) kJ \, kg^{1} \; \frac{1}{2}(30^2 \; 90^2) m^2 s^2 \; x \, 10^3 \; kJ \, kg^1 / (m^2 s^2)$

1237.61 kJ kg^{1}

Pump work,

$W_{pump} \quad h_4 \quad h_3$

$(P_1 \; P_2) v_3$

(70 0.2)bar x 102 kPa bar^{1}

(0.001071 m^3 kg^{1})

7.47558 kJ kg^{1}

Net work,

w_{net} w_{shaft} w_{pump}

(1237.61 7.47558) kJ kg^{1}

1230.13442kJ kg^{1}

State 4(70 bar) :

h_4 h_3 w_{pump}

258.85558 kJ kg

^{1} Heat supplied,

q_{in} h_1 h_4

(3531 258.85558)kJ kg^{1}

3272.14442 kJ kg^{1}

Power produced,

w_{net} $m(w_{net})$

35 kgs^{1} (1230.13442kJ kg

^{1}) 43054.7047 kJ s^{1}

43.054 MW

Thermal efficiency,

$_{therm}$ $\frac{w_{net}}{q_{in}}$

$\frac{1230.13442 kJ\ kg^{1}}{3272.14442 kJ\ kg^{1}}$

0.37594, i.e., 37.59%

Effect of Reheating on Turbine Efficiency

Problem - 3 : Steam (30 bar/400°C) is allowed to expand isentropically in a steam turbine to a pressure of 0.08 bar. Determine the

(a) dryness fraction at the end of the cycle

(b) thermal efficiency of the cycle

Now, if the same feed steam is allowed to expand isentropically upto a pressure limit of 3 bar and then reheated to 380°C and then allowed to expand again, in the turbine to the final pressure of 0.08 bar, determine the

(a) dryness fraction of the steam at the md qf expansion

(b) thermal efficiency of the cycle

Sol: Refer to two h-s diagrams—one without reheating and the other with reheating

Without reheating

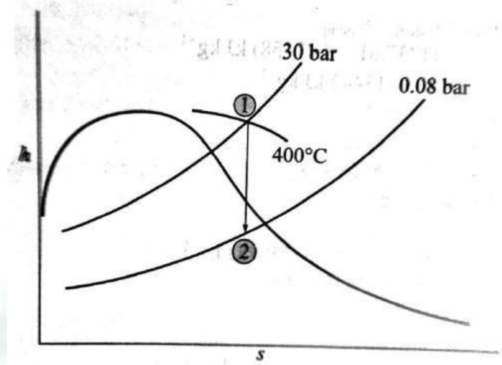
State 1 (30 bar/400_0C):

h_1= 3231 kJ kg^{-1};

s_1= 6.921 kJ kg^{-1} K^{-1}

State 2 (0.08bar) :

$s_2 = s_1$



Isentropic expansion of 30 bar /400°C steam to 0.08 bar (without any reheating).

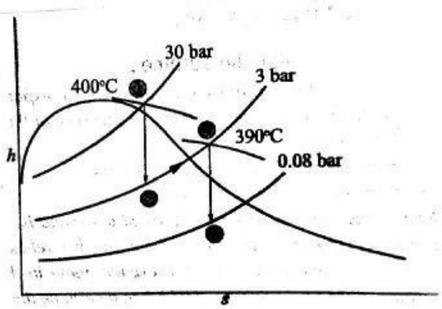
(isentropic expansion of steam in the turbine) Also, $s_1 = s_2 = s_{f2} + x_2 s_{fg2}$

$= 0.5932$ kJ kg_{-1} K_{-1} $+x_2$ (7.6369 kJ kg_{-1} K_{-1}) $x_2 = 0.82858$

$h_2 = h_{f2} + x_2 h_{fg2}$

= 174 kJ kg_{-1} + 0.82858 (2403 kJ kg_{-1})

= 2165.0832 kJ kg_{-1}



Isentropic expansion of 30 bar /400°C steam to 3 bar (wet, saturated) steam which is then reheated to 390°C (superheated steam) before being allowed to undergo final isentropic expansion to 0.08 bar.

Turbine work,

W_{turb} h_1 h_2 (3231 2165.0832) kJ kg ^{1}

1065.9168kJ kg ^{1}

Heat sup plied,

q_{in} h_1 h_{f2}

(3231 174)kJ kg ^{1} 3057kJ kg ^{1}

Thermal efficiency,

w_{net} $\frac{1065.9168 \text{ kJ kg}^{1}}{}$

$^{therm}q_{in}$3057 kJ kg ^{1}

0.348680, i.e., 34.868%

With reheating

State 1 (30 bar/400$_0$C):

h_1= 3231 kJ kg^{-1};

s_1= 6.921 kJ kg^{-1} K^{-1}

State 2 (3bar) :

$s_2 = s_1$ (isentropic expansion of steam in the turbine)

Also, $s_1 = s_2 = s_{f2} + x_2 s_{fg2}$

= 1.672 kJ kg^{-1} K^{-1} +x_2 (5.320 kJ kg^{-1} K^{-1}) x_2 = 0.9866

$h_2 = h_{f2} + x_2 h_{fg2}$

= 565.5 kJ kg$_{-1}$ + 0.9866 (2164 kJ kg$_{-1}$)

= 2696.6195 kJ kg$_{-1}$

State 1 (3 bar/390$_0$C):

s_3= 8 kJ kg^{-1} K^{-1};

h_3= 3254.43 kJ kg^{-1}

State 4 (0.08bar) :

$s_3 = s_4$ (isentropic expansion of steam in the turbine)

Also, $s_3 = s_4 = s_{f4} + x_4 s_{fg4}$

= 0.5932 kJ kg$_{-1}$ K$_{-1}$ +x_4 (7.6369 kJ kg$_{-1}$ K$_{-1}$) x_4 = 0.969869

$h_4 = h_{f4} + x_4 h_{fg4}$

= 640.2 kJ kg$_{-1}$ + 0.969869 (2108.5 kJ kg$_{-1}$)

= 2685.1708 kJ kg$_{-1}$

Turbine work,

W_{turb} h_1 h_2 h_1 h_2

(3231 2696.61954) kJ kg ^{1} (3254.43 2685.1708) kJ kg ^{1}

1103.6396 kJ kg ^{1}

Heat supplied,

q_{in} h_1 h_{f4} h_3 h_2

(3231 640.2)kJ kg ^{1} (3254.43 2696.61954)kJ kg ^{1}

3148.61046 kJ kg ^{1}

Thermal efficiency,

$$_{therm} \frac{w_{net}}{q_{in}} \frac{1103.6396 \text{kJ kg}^{1}}{3148.61046 \text{ kJ kg}^{1}}$$

0.350516, i.e., 35.051%

Effect of Regenerative Feed Heating on Turbine Efficiency

Problem - 4 : Steam (30 bar/300°C)is allowed to expand isentropically in a multi-stage steam turbine to a pressure of 0.06 bar /30° C. The turbine is fitted with two stages of regenerative feed heating. The first tapping is taken at 2 bar. Determine the

(a) Pressure for the second tapping

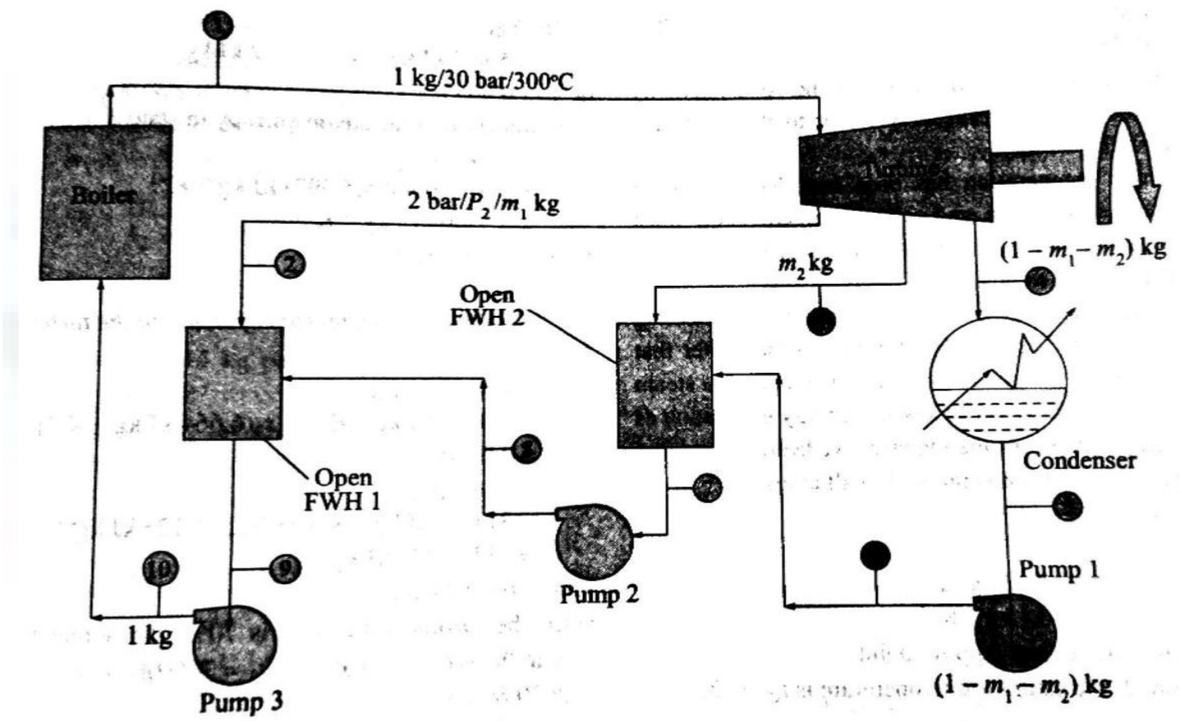
(b) quantities of steam extracted from each point

(c) gain in efficiency due to increase in regenerative feed heating

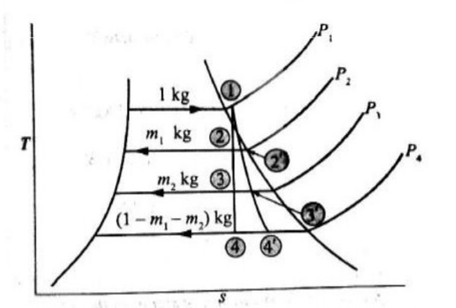
(d) increase in steam consumption rate

Turbine efficiency at each stage = 75 %

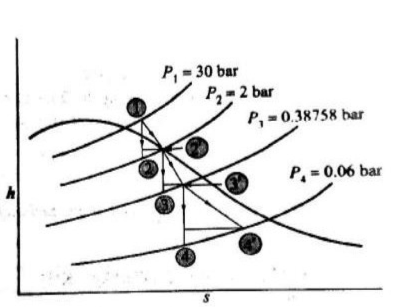
Sol :



The schematic diagram of a multi-stage turbine provided with two stages of regenerative feed heating.



Schematic *T–s* diagram of a multi-stage turbine provided with two stages of regenerative feed heating.



Schematic *h–s* diagram of a multi-stage turbine provided with two stages of regenerative feed heating.

Steam is extracted at two points marked by Point 2 (2 bar/Zym, kg) and Point 3 (m_2 kg/P_3). These two streams are subjected to regenerative heating of the condensate and are then sent to the boiler to boost up the cycle efficiency. The corresponding T-s and h-s diagrams are depicted.

Analysis

1. Expansion of steam in the steam turbine is not isentropic, since the expansion is only 70% efficient.
2. Actual enthalpy drop is to be evaluated by introducing the efficiency factor to the isentropic enthalpy drop.
3. Since regeneration has been introduced, thermal efficiencies with and without regeneration must be evaluated to determine the percentage gain in thermal efficiency.
4. Steam consumption with and without feed heating in the FWH is equally important a parameter that, must be evaluated to project how much extra steam is consumed per extra kWh of energy generation as a consequence of the regenerative heating.
5. Here pump work is ignored in all cases.

Calculations

State 1 (30 bar/300$_0$C):

h_1= 2993.5 kJ kg^{-1};

s_1= 6.539 kJ kg^{-1} K^{-1}

Locating the second tapping point

At point 2, the saturation temperature is t_{s2} = 120.2$_0$c Now,

t_{s2} t_{s3} t_{s3} t_{s4}

t_{s3} $\frac{1}{2}$ t_{s2} t_{s4} t_{s4}

$\frac{1}{2}$ 120.2 30 ^{0} C 30^0 C 75.1^0 C

The saturation pressure corresponding to 75.1$_0$c is 0.387 bar. Hence the second tapping point (Point 3) corresponds to 0.387 bar/75.1$_0$C.

State 2 (2bar) :

$s_2 = s_1$ (for isentropic expansion of steam in the turbine)

Also, $s_1 = s_2 = s_{f2} + x_2 s_{fg2}$

= 1.53 kJ kg^{-1} K^{-1} +x_2 (5.597 kJ kg^{-1} K^{-1})

x_2 = 0.8949

$h_2 = h_{f2} + x_2 h_{fg2}$

= 504.7 kJ kg$_{-1}$ + 0.8949 (2202 kJ kg$_{-1}$)

= 2475.366 kJ kg$_{-1}$

State 2' (2 bar) :

Since the turbine efficiency is 70%, the actual heat drop in the first stage h_1-h_2' =70% (h_1-h_2)

2993.5 kJ kg$_{-1}$

Feedwater Heating.

In most power plants the main condensate returns to the steam generator as feedwater. Some make-up may be added to replace losses in the cycle. In a few plants the boiler feedwater may be 100 per cent make-up; in this case the plant turbines exhaust at back pressures above atmospheric to supply steam for other purposes. Feedwater is heated by bleeding steam to heaters as in a regenerative cycle from the main turbine, or by using exhaust steam from auxiliary-drive turbines, or by by-product steam from processes.

Feedwater heating with steam at a lower pressure than boiler pressure usually raises over-all plant efficiency. Early plants had a simple open heater which received steam from back-pressure turbines or engines driving plant auxiliaries and which heated the main condensate to 212 F at 14.7 psia. Smaller industrial plants still use this scheme.

Modern central stations have as many as ten heaters bleeding steam at successively lower pressures from the main turbine. The condensate and feedwater flow through these to be heated in steps to feedwater temperature.

Feedwater heaters may be classified as: (1) open, direct-contact, or mixing heaters (simple or deaerating) or (2) closed, noncontact, or surface heaters. Heated feedwater enables steam generators to produce more pounds of steam and avoids severe thermal stressing by cold water entering a hot drum. Preheating feedwater also causes scale-forming dissolved salts to precipitate outside the boiler and/removes dissolved oxygen and carbon dioxide, which corrode boiler metal.

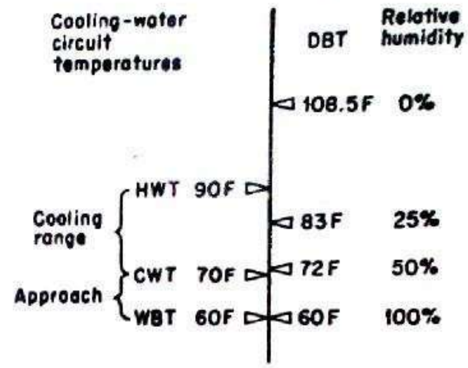
State the function and types of cooling tower.

Cooling Towers. More power stations are being built in water-short areas. Lack of large water flows makes these plants rely on cooling towers to remove heat energy from the circulating water flowing in a closed circuit.

Of the variety of cooling-tower designs available the induced-draft (I-d) tower finds the widest application in central stations. Sections through a four-cell tower. Air enters the side louvers to flow around the wood filling and up through the i-d fans at the top of the tower.

Hot circulating water from the condenser outlet enters the distributing header at the tower top to flow into the distributing basins forming the roof of the tower. From these the water flows through many holes to fall on the wood-fill strips below. This breaks up the water into small drops and spreads the water in thin films on the fill surface as it cascades to the collecting basin at the bottom.

As the water falls in drops from strip to strip, it exposes a maximum surface to speed evaporation and heat transfer. The drops fall through the cross-and counter-air flow that carries away the vapor and heat as they are released from the water surface.



The water cools by (1) evaporation and (2) heat transfer to the air. In many towers about 75 per cent of the cooling takes place by evaporation sad the remainder by heat conduction; the ratio depends on the humidity the entering air and various design factors.

Vapor separating from a non boiling laid always leaves behind a cooler liquid because the vapor is composed of the higher-energy molecules originally in the liquid. In addition the (cooler air picks up heat by conduction from the warmer water.

Tower cooling performance is always referred to the wet-bulb temperature of the incoming air. This is the lowest temperature that the outgoing water can be cooled to. The finite dimensions of a tower and the limited time in which water and air contact each other make it impossible to achieve this ideal cooling.

The principal performance factor of a tower is its approach to the wet-bulb temperature; this is the difference between the cold-water temperature leaving the tower and the wet-bulb temperature of the entering air. The smaller the approach, the more efficient the tower. Another important performance factor is the cooling range; this is the difference between the hot-water temperature entering the tower and the cold-water temperature leaving. It gives a graphic demonstration of these factors for a given tower.

The scale to the right of the dry-bulb temperatures and relative humidities that correspond to a wet-bulb temperature of 60 F. If the humidity is low enough, a tower can cool water very effectively even with a high dry-bulb temperature.

Make-up must be continuously added to the tower collecting basin to replace the water lost by evaporation and spray carryover. As mentioned before, this nearly equals the amount of steam exhausted by the turbine. The circulating-water circuit must be blown down periodically to remove the accumulated solids concentrated by the evaporation. The water must be treated to kill algae, preserve the wood fill, and prevent metal corrosion.

CHAPTER -3

NUCLEAR POWER STATIONS

Clasicify Nuclear fuel (fissile & fertile material)

Certain heavy atoms are in a precarious state of internal balance, to the extent that by inducing a neutron to enter their nuclei they will Session into two smaller nuclei, eject two or three neutrons, and the fragments emit a gamut of rays: alpha, beta, and gamma. The energy comes from a minute fraction of the original mass converting according to Einstein's famous law: $E = mc^2$, where E represents energy, m mass, and c the speed of light. Most of this energy in fusion appears as internal energy of the fission fragments, while the kinetic energy of the neutrons and the radiations quickly converts to internal energy in the materials that absorb them.

In nuclear fuels the energy comes from disappearance of mass from the nuclei of the atoms. Any atom can be fissioned in an accelerator or similar device for energy release. But in a practical fuel we can do this only when it can sustain a chain reaction. This means that when an atom fissions, the neutrons ejected will be absorbed by other heavy atoms to fission in turn. When I this condition prevails, a mass of nuclear fuel can be used as a source of heat energy.

The only natural substance that will function as a nuclear fuel is uranium. In pure form it is a heavy, hard nickel-white metal—it oxidizes in air and water. Uranium is widely distributed as an oxide ore in concentrations of less than 0.3 per cent throughout the richest deposits lie in the Belgian Congo, northern Canada, and the Colorado Plateau in the United States. Natural uranium wherever found consists of:

Uranium 238 ………	99.3%
Uranium 235 ……….	0.7%
Uranium 234 ….	Trace

Of these three nature' isotopes only uranium 235 (U-235) will fission in a chain reaction. A small portion of the U-238 will also fission when absorbing a neutron, but it cannot sustain a chain reaction.

Man-made Fuels.

To sustain a chain reaction in natural uranium, the fast neutrons Met be moderated (slowed down) to thermal speeds. This is done by letting neutrons collide several hundred times with nuclei of other light atoms, such as hydrogen, helium, beryllium, or carbon. When a thermalized neutron passes close to a U-235 nucleus, the short-range attractive forces have time to pull the neutron into the nucleus and initiate fission. Highly enriched uranium will sustain a chain reaction without a moderator, i.e., with fast neutrons.

Thorium 232, a natural material, can also be converted to a fissionable material by placing it close to U-235, sustaining a chain reaction. By absorbing an excess neutron Th-232 changes to protactinium 233 (Pa-233) and ultimately to U-233 during a process with a half-life of about 271/2 days and during which it emits a gamma ray and two beta particles. Uranium 233 can be fissioned by either fast or thermal neutrons and can sustain a chain reaction like U-235 and Pu-239. Uranium 238 and thorium 232 are called fertile materials.

Explain nuclear reactor.

To control the "burning" of fissionable fuels, they must be placed in a reactor which largely functions to control the release and absorption of neutrons during a chain reaction. Neutrons released in a chain reaction are disposed of in four different ways:

(1) Escape from the fissionable material;

(2) Nonfission capture by U-238 to from Pu-239;

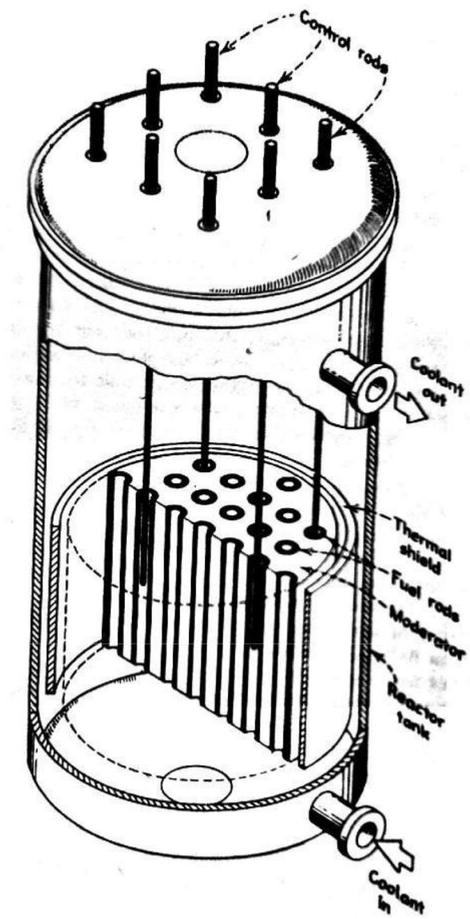
(3) Nonfission capture by control-rod material, moderator nuclei, fission fragments, and impurities; and

(4) fission capture by U-235, and U-233.

A chain reaction producing a constant rate of heat energy can continue only if the neutrons released by fission just balance the four types of disposal listed above. If neutron production rate drops below disposal rate, the chain reaction stops; if it exceeds disposal rate, fissioning rate increases and may get out of control. A reactor is of critical size when the fission-produced neutrons just balance those disposed of in the four/ categories. M For a practical reactor the fissionable fuel in it must be larger than the critical size.

Control Rod.

To regulate fissioning (heat production) in a reactor, control rods of boron or hafnium, neutron-absorbing materials, are inserted into the fuel To increase the fissioning rate of a chain reaction, the control-rod pene¬tration is reduced a small fraction of an inch so that the control rods absorb fewer neutrons, which are then available to fission more atoms in given time. This allows the fissioning rate to increase. When the new fissioning rate has been established, the control rods are again reinserted into the fuel to absorb the excess neutrons and keep the chain reaction from growing further, and so maintain the new higher rate. To lower the fissioning rate, the control rods are pushed deeper into the fuel to absorb more of the neutrons. When fissioning has dropped to the lower rate, the rods are pulled out to their former position.



Fuel Rod.

The reactor core, made up of the fuel rods or assemblies, may contain natural uranium metal, enriched uranium, plutonium, or U-233. The fuel rods may be diluted with nonfissionable material to get better reac¬tion control or to minimise damage from fission-product poisoning. The fuel rods may be machined or rolled into a variety of shapes such as tubes sheets, rods, balls, or powders. They must be clad with a corrosion-resisting metal, such as aluminum, stainless steel, or zirconium. The fuel may also be uranium oxide pellets held in a container made of the metals just mentioned for cladding. Fissioning makes the fuel Is hot and produces temperatures of the order of 1100 F.

Moderator

The moderator in a reactor core consists of a material, such as graphite, round the fuel to slow the fast neutrons to a thermal speed. In reactors the moderator may be mixed with the fuel. The moderator be pure graphite, heavy water, or light (normal) water. Fast neutrons with an energy level of about 1 million electron volts (1 mev) travel a few inches at speeds of about 8,700 mps. Moderators reduce this speed to a thermal level of about 2 mps in a very small fraction of a second.

Thermal shielding

It must surround the entire reactor core to absorb some of the radiations (beta particles, escaping neutrons, and gamma rays) produced by the fissioning. The shield, usually made of iron, partly absorbs these energy forms and becomes heated. This prevents the adjacent wall of the reactor vessel from becoming locally heated and warped. The coolant flows over the thermal shield to carry off the generated heat.

Reflector

It usually completely surrounds the reactor core within the thermal shielding. It bounces back most of the neutrons that escape from the fuel core. The outer edges of the moderator also functions a reflector. Neutrons colliding with the atoms of the reflector heat it, so that it also must be cooled. It provides the passage for directing the coolant flow through and around the reactor core.

The reactor vessel, or tank, completely encloses the reactor core with reflector and thermal shield. The vessel may have to withstand pressures of only a few 100 ib/in2 or pressures as high as 3,000 psi. The reactor core sits near the vessel bottom to give room for maneuvering the fuel-handling gear above the core. Fuel assemblies (rods) enter and leave the vessel through an access hole at the top. In some water-cooled reactors these fuel assemblies can be manipulated manually through the access door by long tongs.About 15 ft of water must be maintained as a shield between the radio¬active fuel and the operators handling it. There are one or more inlet nozzles at the tank bottom to admit coolant flow and one or more nozzles at the upper edge to discharge coolant flow.

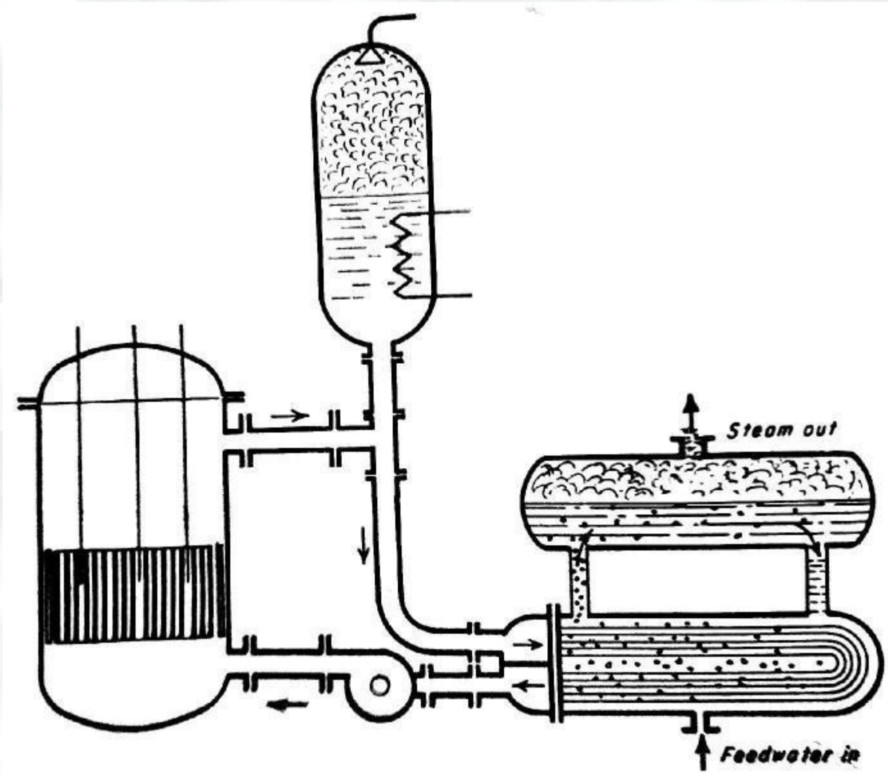
Pressurized-water Reactor.

The arrangement a pressurized-water reactor (PWR) that uses either heavy or light water as both moderator and coolant. The water completely fills the reactor vessel, heat-exchanger tubes of the boiler, and connecting pipe- lines. The pressurizing tank keeps the water at more than 1,200 psig so that it will not boil.

Electric heating coils in the pressurizer boil off some of the water to form steam that collects in the dome. As mart steam is forced into the dome by boiling, its pressure rises and so pressurizes the entire coolant circuit. To reduce pressure, cooling coils or spray water condenses some of the steam.

The pump circulates the coolant Into the bottom of the reactor vessel, up through the core passages and over the reflector and thermal shield, out through the outlet nozzle into the heat-exchanger section Of the boiler, then out to the pump suction to complete the circuit. The only circulates the coolant (does not pressurize it) by generating pressure rise just enough to overcome the flow resistance of the circuit.

As the coolant flows upward through the core, it is heated by the fissioning fuel elements. Some local steam bubbles may form at hotter spots of the fuel elements, but they quickly condense in giving up their heat to the surrounding water coolant. The hot coolant gives up its energy by heat transfer to the feed water returned from the turbine condenser, in the heat-exchange section of the steam boiler. The cooled coolant then returns to the reactor vessel for reheating.



Pressurized- water reactor has pump circulating water between reactor vessel and boiler heat exchanger. Water acts as coolant and moderator. Pressurizing tank maintains water pressure.

The coolant becomes radioactive in passing through the reactor core, So that the entire coolant circuit, including the steam generator, must be shielded to protect operating personnel. The radioactive coolant does not have the ability to make the steam in the boiler radioactive.

With the pressurized coolant at about 2,000 psig the highest-pressure steam is limited to about 600 psig leaving the boiler. This reactor arrangement can produce only saturated steam. The steam, however, can be superheated by separate firing after leaving the boiler.

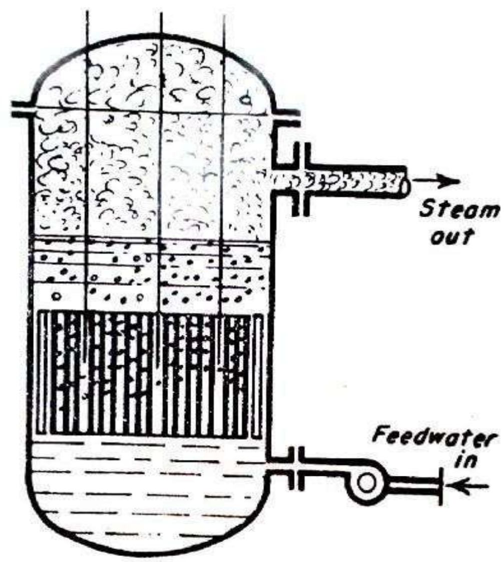
Boiling-water Reactor.

The boiling-water reactor (BWR), the simplest form of nuclear reactor. Feed water returning from the turbine enters the bottom of the reactor vessel to join water in the reactor circulating upward through the core and downward over the thermal shield around the core periphery.

Steam bubbles form on the surfaces of the fuel elements and are carried upward in the circulating water to break through in the steam-release space above. The steam then leaves to enter the turbine. The water acts as both coolant and moderator.

Steam pressure in this reactor need be only at the working pressure used by the turbine. The reactor vessel can be much lighter than that for a PWR. This reactor does not need a pressurizer, steam generator, circulating pump, or connecting piping. The steam will be hotter because of eliminating temperature drops in a separate steam generator and because it can be produced at a higher pressure.

Steam leaving this reactor will be radioactive, but at a low level and with a half-life on the order of 15 min. The turbine and its piping need light shielding to protect personnel.

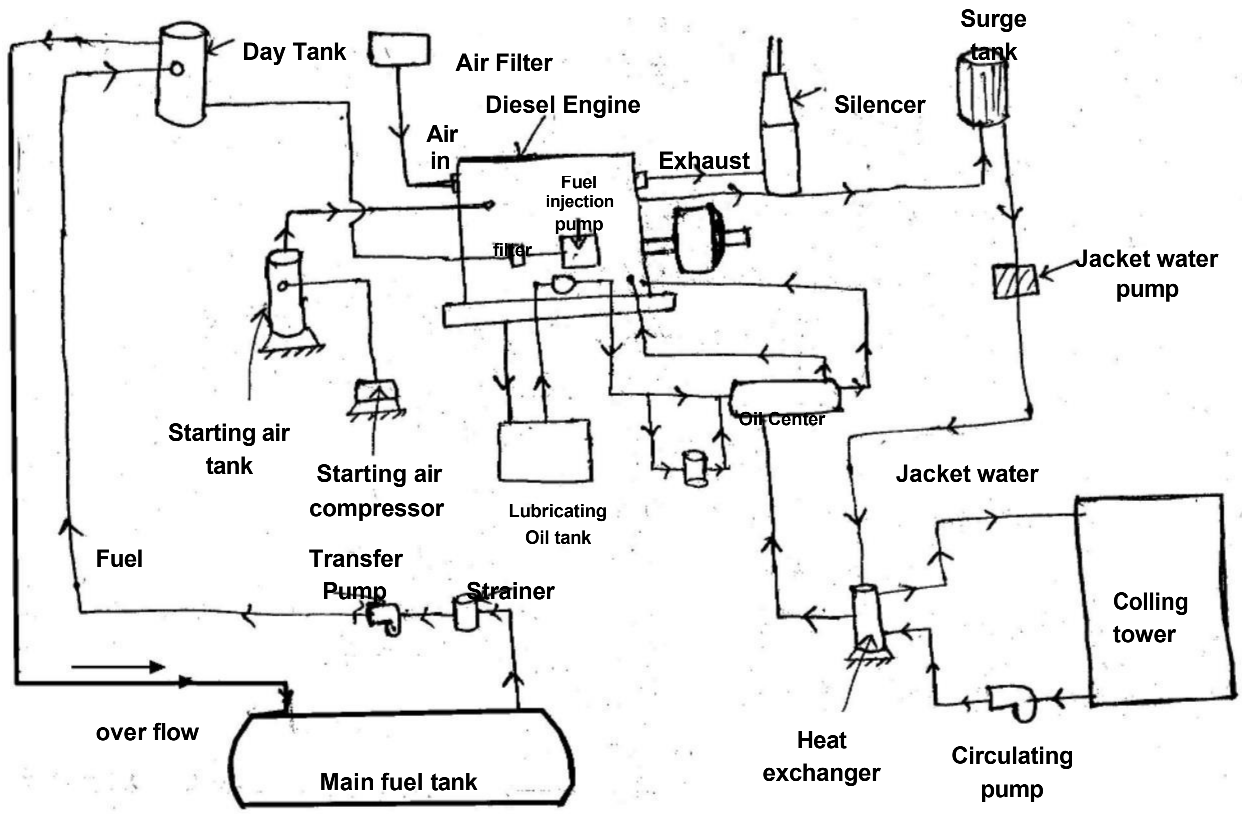


In boiling-water reactor coolant water, also acting as moderator, circulates upward through fuel core and downward over thermal shield. Steam bubbles break through water surface— steam collecting in upper vessel leaves for turbine. Feedwater replaces steam generated.

CHAPTER - 4.0

DIESEL ELECTRIC POWER STATION

Diesel power plant



General layout of diesel power plant

Explain essential of diesel power plant & there function

Diesel power plant can be used as base load plant, peak load plant or stand by unit. The diesel power plants are more efficient than any other heat engine of comparable size. It is cheap in first cost. It can be started quickly and brought into the service. Its manufacturing periods are short. The diesel power plant consists of the following components.

1. Engine:

It is the main component of the plant which develops required power. It is directly coupled to the generator. It is a four stroke diesel engine using diesel as fuel.

2. Air filter and super charger:

The function of the air filter is to remove the dust from the air which is supplied to the engine. The function of the super charger is to increase the pressure of the air supplied to the engine to increase the power output. The super charger are generally driven by the engine shaft.

3. Exhaust system:

This includes the exhaust valve, exhaust manifold and silencer. During the exhaust stroke, the burnt gases are exhausted to atmosphere through the exhaust manifold and silencer.

4. Fuel supply system:

This includes the main fuel tank, day tank, fuel pump, transfer pump, oil filter and fuel valve. The fuel is injected into the engine cylinder with the help of a fuel injector pump. The filter is used to remove the dust and dirt from the fuel supplied to the engine.

5. Cooling system:

This system includes surge tank, heat exchanger, jacket water pump, cooling tower and cooling water circulating pump. The purpose of the cooling system is to carry the heat from the engine cylinder to keep the temperature of the cylinder in the safe range and extend the life of the engine. In order to cool the engine, water is circulated through the engine jacket and warm jacket water is cooled by passing the water through the heat exchanger. In the heat exchanger the warm jacket water is cooled by the cooling water coming from the cooling tower. The surge tank is provided to reduced the water hammering effect.

6. Lubricating system:

It includes oil pump, oil tank filter, coolers. The function of the lubrication system is to reduced the friction of the moving parts and thus reduce the wear and tear of the engine part.

7. Starting system:

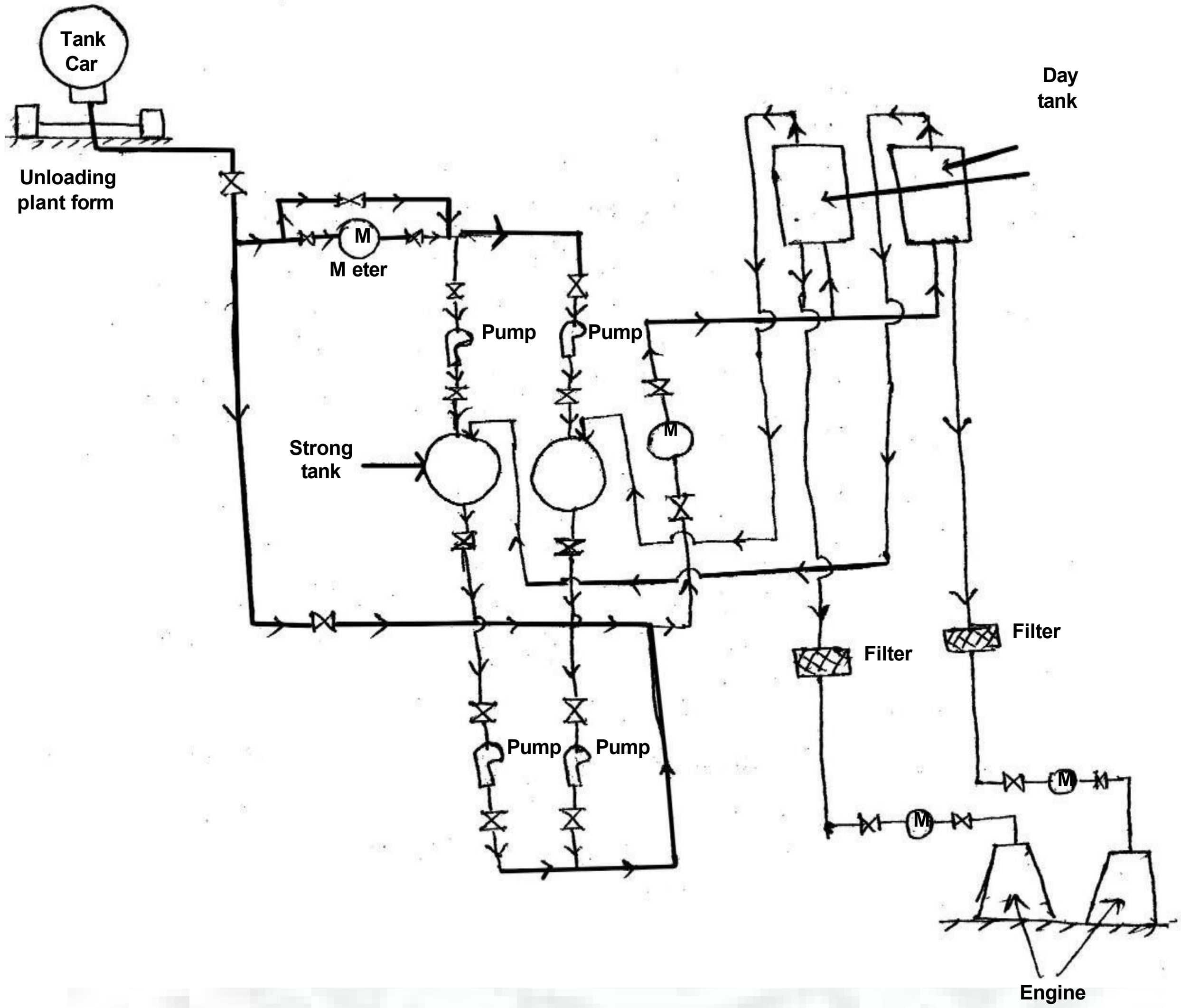
It includes compressed air tank and air compressor. The function of this system is to start the engine from the cold by applying the compressed air.

8. Governing system:

The function of the Governing system is to maintain the speed of the engine constant irrespective of load on the plant. This is done by varying fuel supply to the engine according to the load.

Different systems of diesel power plant

Fuel storage and fuel supply system



Bulk storage tank and engine day tanks hold the engine fuel oil. The former receive the oil delivered to the plant and stant outdoorsd for safety. Pumps draw oil from the storage tank to supply the smaller day tanks in the plant at daily or shorter intervals. Tanks must have manholes for internal access and reapair. Fill lines to receive oil vent line to discharge vapours, sounding connections to major content, overflow return lines fro controlling oil flow and a suction line to withdrawal oil. Coils heated by hot water or steam reduced oil viscosity to lower pumping power needs. Delivered oil sometimes holds water, dirt, metalic chips, and other foreign matter that must be removed by filtering or centrifuging.

The fuel storage and fuel supply system depend upon the type of fuel, size of the plant and type of engine used. The fuel supply system is generally classified as a) Simple suction system and b) transfer system.

In simple suction, the oil is taken by a suction pump driven by engines from service tank located of few Cm below the engine level. Such pump delivers constant volume of fuel, therefore an over flow line is required back to the tank. This system is used for small capacity plant.

In transfer system, the pump delivers fuel from the underground storage to day storage tank. The fuel from the day storage tank flows under gravity to engine fuel pump. This type of system is used for medium size or large size plant.

The location of storage tank above or below the ground depend upon the local conditions. The over ground tank has the advantage of detecting leak easily, low maintenance and easy cleaning. The underground tank has the advantages of reduced fire hazards.

Fuel Injection System :

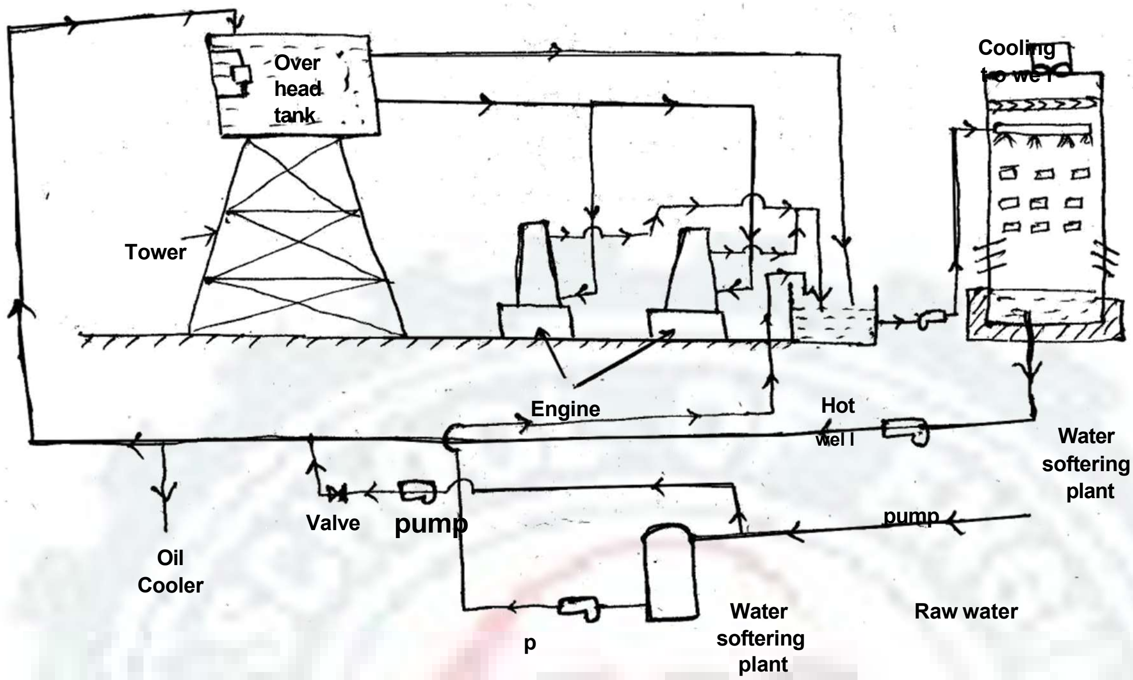
The function of the fuel injection system is to meter the fuel, inject into cylinder at proper time, atomize the fuel and mixes the fuel with air. The efficiency of the engine depends upon the proper mixing of fuel with air. Generally solid injection is used. The fuel at a pressure of 100 to 200 ata is injected through the nozzle into the compressed air which also helps to atomise the fuel. The common method which are used for fuel injection system are individual pump, common rail and distributor system.

Air Supply System :

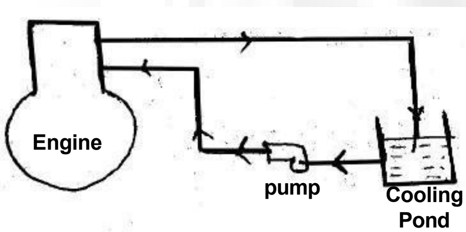
A large diesel power plant requires large amount of air as 4 to 8 m^3/kwhr. The air contains dust which is to be removed from the air before supplying to the engine. Otherwise it causes excessive wear and tear in the engine. The intake of the air supply system is located outside the building provided with filters. The filters used may be oil impingement, oil bath or drag type depending upon the dust type and dust concentration in the air.

Water Cooling System :

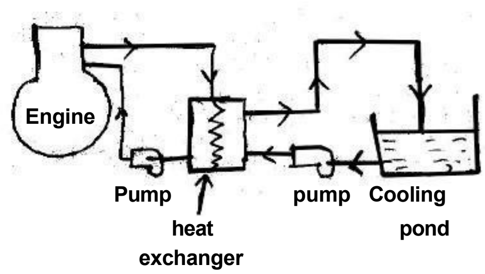
If the engines are not properly cooled, the temperature inside the engine would burn the lubricating oil on the liners. Thus wrapping of valves and piston takes place. The proper cooling of the engine is absolutely necessary to extend the life of the plant. Therefore exit temperature of the cooling water must be controlled. If it is too low the lubricating oil will not flow properly and wearing of piston and cylinder takes place. If it is too high, the lubricating oil burns.



A common water cooling system used in diesel power plant is shown in figure. In this system it is necessary to soften the water otherwise it may cause deposits at temperature at 500C. Generally the quantity of cooling water required is 35 to 60 litres per kw per hour. In order to cool the engine, water is passed through the engine jacket. The warm water coming from the engine is cooled in the cooling tower. The cooling water from the cooling tower is then supplied to the overhead tank. From the overhead tank water flows under gravity to the engine jacket. The circulation of water is generally divided into a single circuit system and double circuit system. Two systems are shown in figure. The single circuit system may be subjected to corrosion in the cylinder jacket as cooling water from cooling.



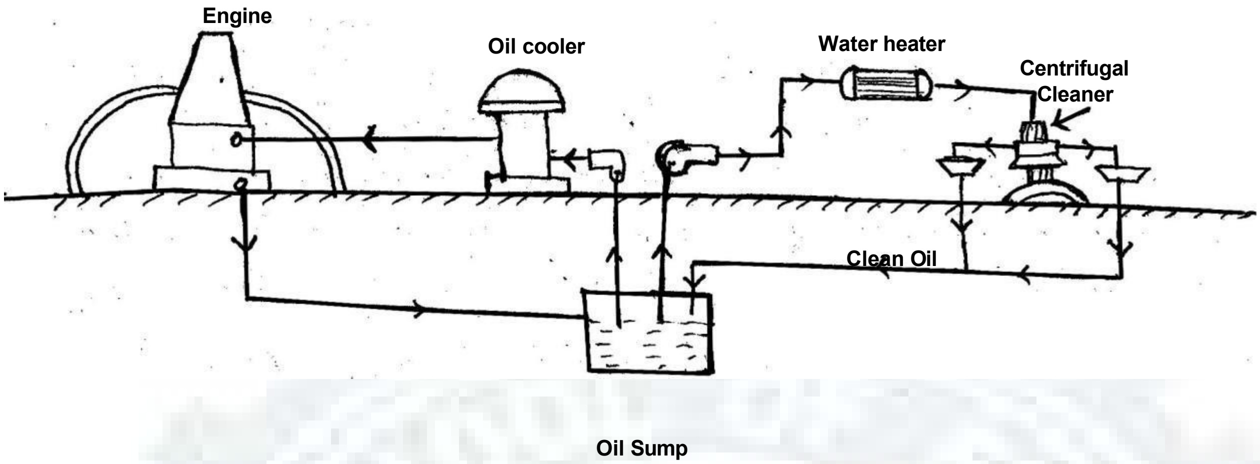
Single circuit cooling system



Double circuit cooling system

Pond is directly supplied to the engine. But in double circuit system the jacket water is cooled by the cooling water coming from the cooling pond in the heat exchanger. This eliminator internal jacket corrosion.

Lubrication System :



The lubricating oil or lube oil, performs several duties :

1. It lubricates moving parts
2. Removes heat from cylinder and bearings
3. Help piston rings to seal gases in the cyliner
4. Carries away solid matter from rubbing moving parts.

Lube oil must choosen with care and purified at intervals.

The lubrication system in diesel power plant is more important than other plant because of very high pressure and small clearance in the diesel engines. The life of the engine, overall thermal efficiency depend upon the effectiveness of the lubrication system. The main parts to be lubricated are crankshaft, wrist pin, bearings and all other moving parts. Pressure lubrication is generally used. This system includes oil sump, pump, oil cleaner, heater and safety devices. The lubricating oil is cooled in an oil cooler before supplying to the engine. The cooling is done by using the water coming from the cooling tower. It is necessary to remove the impurities in the form of carbon particles, water and metal scrap carried by the oil during circulation. For this purpose, filters or centrifugal cleaners are used. The mechanical type of filters used are cloth bags, wood pads, paper pads and porous material pads. For high capacity plant, centrifugal cleaners are used as the quantity of lubricating oil circulated is approximately 2000 litres per hour for 1 MW plant. The oil should be heated before passing through the centrifugal cleaner inorder to increase the fluidity of the oil.

Starting System : It is difficult to start the diesel engine by hand as the compression pressure are extremely high. Therefore some mechanical systems are used to start the engine. Generally, compressor air electric motors and petrol engines are used for starting the engine. Compressed air system is commonly used for large capacity diesel plants. This system supplies the air under high pressure to a few of the cylinders, making them to act as reciprocating air motors to turn the engine shaft.

Admitting fuel oil to the remaining engine cylinders helps the engine to start under its own power. The compressor is driven by the engine shaft. The compressed air is accumulated in the air tank. Once the accumulators indicate the rated pressure, the compressors are automatically disconnected from the power shaft.

Advantages of Diesel power plant over thermal power plant :

1. It is more efficient than steam power plant in the range of 150 MW capacity.
2. It is cheaper in first cost than steam plant up to about 7 KW. Above this capacity, diesel cost rises rapidly where as steam plants continues to fall.
3. It has no stand by losses.
4. It can be started quickly & brought into service.
5. Manufacturing periods are short.
6. Maintenance can be simplified by the provision of easily replaceable assemblies of parts.
7. It is possible to instal compact, light weight, high speed diesel set for sites that are remote.
8. The cooling water required for the same capacity is considerably less than the thermal plant.
9. The diesel plants can be located very near to the load centre, many times in the heart of the town.
10. The space required for diesel plant is considerable less than thermal plant.
11. The storage required for fuel is less than thermal plant.
12. There is no problem of ash handling.
13. The plant layout is very simple compared to thermal plant.

Disadvantages :

1. The unit capacity of diesel plant is less than thermal plant.
2. The cost of unit increases with an increase in unit capacity for diesel plant where as the cost of unit decreases with the increase in unit capacity for thermal power plant.
3. The repair & maintenance are generally much higher than thermal power plant.
4. Life of diesel plant is much less as compared to thermal plant.
5. The noise is a serious problem in diesel plant.
6. The lubrication cost is high.
7. The diesel plants are not guaranteed for continuous operation under overloads & where as steam power plants can work under 25% overload continuously.

CHAPTER-6

GAS TURBINE POWER STATION

INTRODUCTION

The gas turbine obtains its power by utilizing the energy of burnt gases and air, which is at high temperature and pressure by expanding through the several ring of fixed and moving blades. It thus resembles a steam turbine. To get a high pressure (of the order of 4 to 10 bar) of working fluid, which is essential for expansion a compressor, is required. The quantity of the working fluid and speed required are more, so, generally, a centrifugal or an axial compressor is employed. The turbine drives the compressor and so it is coupled to the turbine shaft. If after compression the working fluid were to be expanded in a turbine, then assuming that there were no losses in either component the power developed by the turbine would be just equal to that absorbed by the compressor and the work done would be zero. But increasing the volume of the working fluid at constant pressure, or alternatively increasing the pressure at constant volume can increase the power developed by the turbine. Adding heat so that the temperature of the working fluid is increased after the compression may do either of these. To get a higher temperature of the working fluid a combustion chamber is required where combustion of air and fuel takes place giving temperature rise to the working fluid. Thus, a simple gas turbine cycle consists of

(1) A compressor,
(2) A combustion chamber and
(3) A turbine.

Since the compressor is coupled with the turbine shaft, it absorbs some of the power produced by the turbine and hence lowers the efficiency. The network is therefore the difference between the turbine work and work required by the compressor to drive it.

Gas turbines have been constructed to work on the following: oil, natural gas, coal gas, producer gas, blast furnace and pulverized coal.

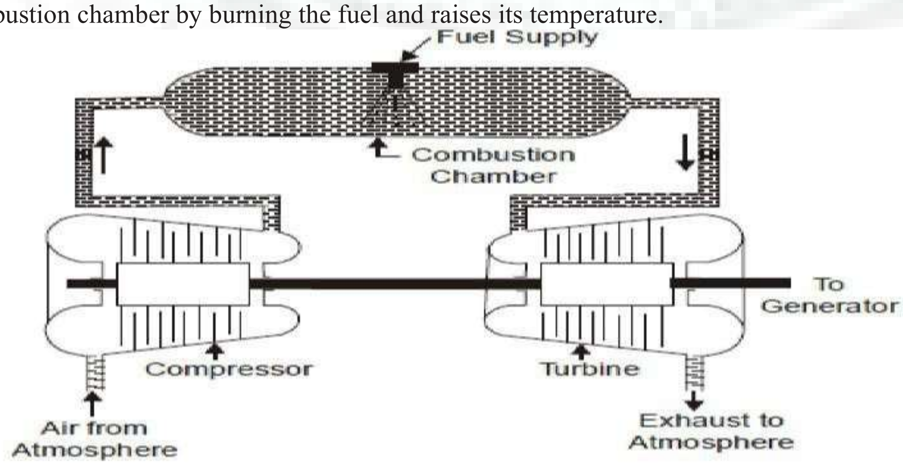
CLASSIFICATION OF GAS TURBINE POWER PLANT

The gas turbine power plants which are used in electric power industry are classified into two groups as per the cycle of operation.

(a) Open cycle gas turbine.
(b) Closed cycle gas turbine.

OPEN CYCLE GAS TURBINE POWER PLANT

A simple open cycle gas turbine consists of a compressor, combustion chamber and a turbine as shown in Fig.. The compressor takes in ambient air and raises its pressure. Heat is added to the air in combustion chamber by burning the fuel and raises its temperature.



Open cycle gas turbine.

The heated gases coming out of combustion chamber are then passed to the turbine where it expands doing mechanical work. Part of the power developed by the turbine is utilized in driving the compressor and other accessories and remaining is used for power generation. Since ambient air enters into the compressor and gases coming out of turbine are exhausted into the atmosphere, the working medium must be replaced continuously. This type of cycle is known as open cycle gas turbine plant and is mainly used in majority of gas turbine power plants as it has many inherent advantages.

STATE ADVANTAGES & DISADVANTAGES OF GAS TURBINE PLANT

Advantages

1. **Warm-up time.** Once the turbine is brought up to the rated speed by the starting motor and the fuel is ignited, the gas turbine will be accelerated from cold start to full load without warm-up time.
2. **Low weight and size.** The weight in kg per kW developed is less.
3. **Fuels.** Almost any hydrocarbon fuel from high-octane gasoline to heavy diesel oils can be used in the combustion chamber.
4. Open cycle plants occupy comparatively little space.
5. The stipulation of a quick start and take-up of load frequently are the points in favour of open cycle plant when the plant is used as peak load plant.
6. Component or auxiliary refinements can usually be varied to improve the thermal efficiency and give the most economical overall cost for the plant load factors and other operating conditions envisaged.
7. Open-cycle gas turbine power plant, except those having an intercooler, does not require cooling water. Therefore, the plant is independent of cooling medium and becomes self-contained.

Disadvantages

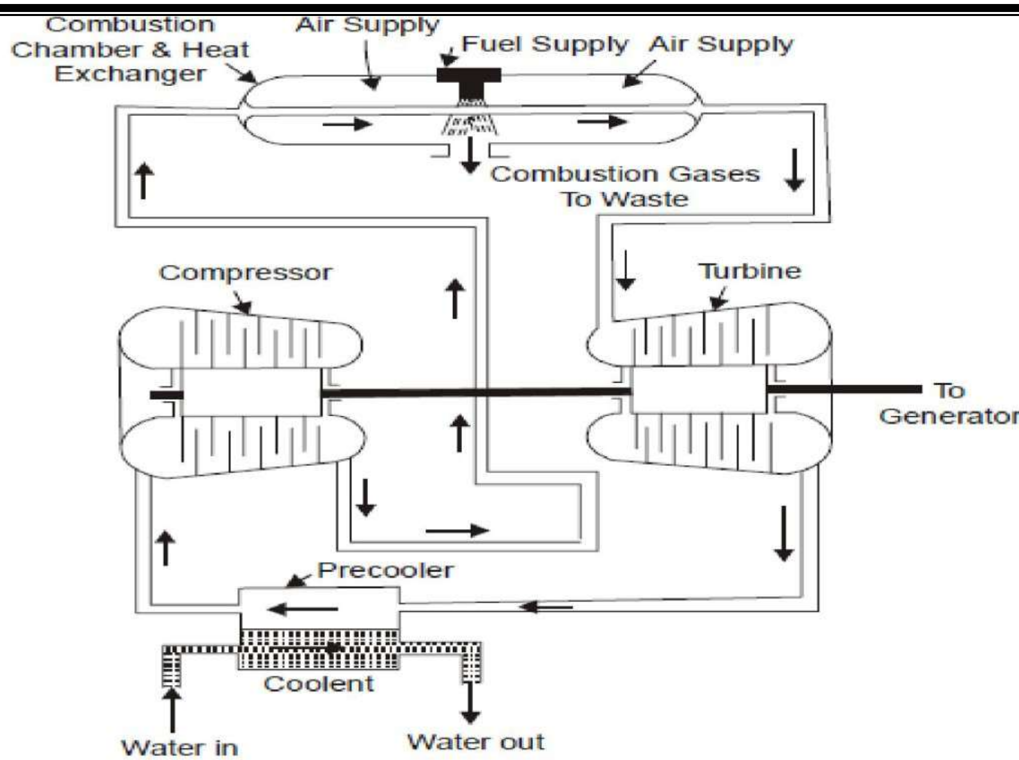
1. The part load efficiency of the open cycle plant decreases rapidly as the considerable percentage of power developed by the turbine is used to drive the compressor.
2. The system is sensitive to the component efficiency; particularly that of compressor. The open cycle plant is sensitive to changes in the atmospheric air temperature, pressure and humidity.
3. The open-cycle gas turbine plant has high air rate compared to the other cycles, therefore, it results in increased loss of heat in the exhaust gases and large diameter ductwork is necessary.
4. It is essential that the dust should be prevented from entering into the compressor in order to minimise erosion and depositions on the blades and passages of the compressor and turbine and so impairing their profile and efficiency. The deposition of the carbon and ash on the turbine blades is not at all desirable as it also reduces the efficiency of the turbine.

CLOSED CYCLE GAS TURBINE POWER PLANT

Closed cycle gas turbine plant was originated and developed in Switzerland. In the year 1935,J. Ackeret and C. Keller first proposed this type of machine and first plant was completed in Zurich in 1944.

It used air as working medium and had a useful output of 2 mW. Since then, a number of closed cycle gas turbine plants have been built all over the world and largest of 17 mW capacity is at Gelsenkirchen, Germany and has been successfully operating since 1967. In closed cycle gas turbine plant, the working fluid (air or any other suitable gas) coming out from compressor is heated in a heater by an external source at constant pressure. The high temperature and high- pressure air coming out from the external heater is passed through the gas turbine. The fluid coming out from the turbine is cooled to its original temperature in the cooler using external cooling source before passing to the compressor.

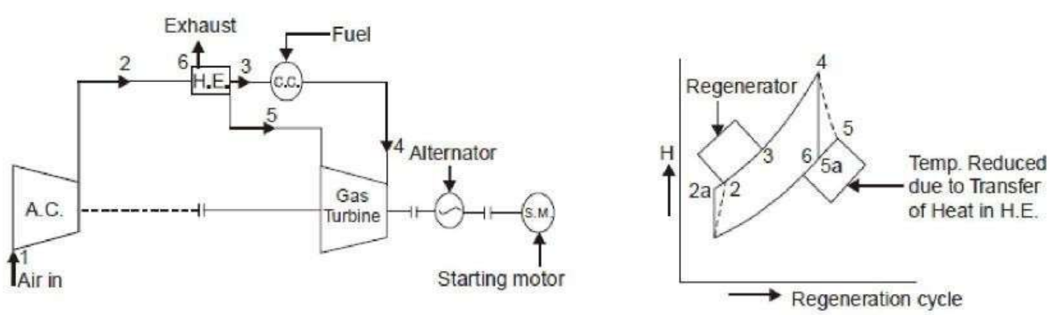
The working fluid is continuously used in the system without its change of phase and the required heat is given to the working fluid in the heat exchanger.



CLOSE CYCLE GAS TURBINE

REGENERATION

In regeneration, the heat energy from the exhaust gases is transferred to the compressed air before it enters the combustion chamber. Therefore, by this process there will be a saving in fuel used in the combustion chamber if the same final temperature of the combustion gases is to be attained and also there will be a reduction of waste heat. Fig..shows a regenerative cycle.



For regeneration to take place T5 should be greater than T2.
In the heat exchanger, the temperature of air is increased from T2 to T3, and the temperature of the exhaust gases is reduced from T5 to T6. If the regeneration is perfect, the air would be heated to the temperature of the exhaust gases entering the H.E. the effectiveness of the regeneration is defined as:

= =

E= effectiveness

For ideal regeneration,
$T_3 = T_5$ and $T_6 = T_2$

The common values of effectiveness would be from 70 to 85%. The heating surface of the generator, as well as the dimensions and price of the gas turbine increases with the regeneration fraction. But to justify the regeneration economically, the effectiveness should atleast be 50%. The regenerative cycle has higher efficiency than the simple cycle only at low- pressure ratios. If the pressure ratio is raised above a certain limit, then the regenerator will cool the compressed air entering the combustion chamber instead of heating it and the efficiency of the regenerative cycle drops.

The compressor turbine works are not affected by regeneration.

However, the heat to be supplied in the combustion chamber is reduced and also it is added at higher temperature as compared to the cycle without regeneration. Thus, the thermal Efficiency of the cycle increases. It will be equal to,

$$\eta_t = \frac{C_p\,(T_4 - T_5) - C_p\,(T_2 - T_1)}{C_p\,(T_4 - T_3)}$$

For ideal regeneration, $T_3 = T_5$

$$\eta_t = 1 - \left[\frac{(T_2 - T_1)}{(T_4 - T_5)}\right]$$

This equation will get reduced to,

$$\eta_t = 1 - \left[\left(\frac{T_1}{T_4}\right)\cdot\left(\frac{1}{(\eta_{ac}\eta_{at})}\right)\cdot(r_p)^{(k-1)/k}\right] \quad ...(1)$$

For ideal open cycle, $\eta_{ac} = \eta_{at} = 1$

$$\eta_t = 1 - \left[\left(\frac{T_1}{T_4}\right)\cdot(r_p)^{(k-1)/k}\right] \quad ...(2)$$

The regenerator should be designed properly to avoid any substantial.
Pressure loss in it, which might cancel out any gain in thermal efficiency. Because of some pressure loss in the regenerator, the turbine output and the net output will be slightly less than for the simple cycle.

REHEATING

In reheat cycle, the combustion gases are not expanded in one turbine only but in two turbines. The exhaust of the high-pressure turbine is reheated in a reheater and then expanded in a low-pressure turbine. By reheating, the power output of the turbine is increased but the cost of additional fuel may be heavy unless a heat exchanger is also used. A reheat cycle is shown in Fig..

Considering the adiabatic expansions, the total work done in the two turbines will be equal to: (I3 – I4*a*) + (I5 – I6*a*).

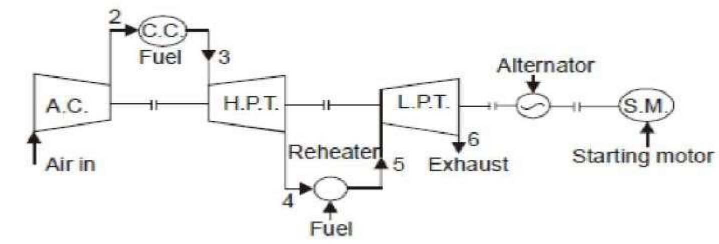
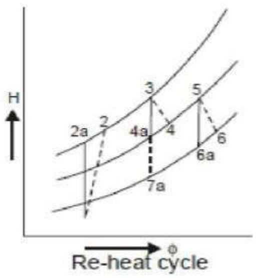
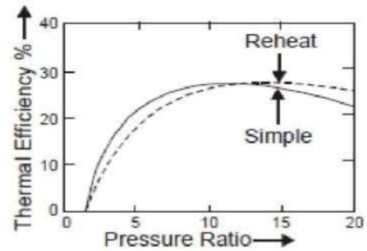


Fig. 9.13





If the combustion gases were expanded in one turbine only down to point 7*a* for the same pressure ratio, then the work output would have been: (I3 – I7*a*).

Now the constant pressure lines on the H-Φ chart diverge away from the origin and converge towards the origin. Therefore the line 5–6*a* will be greater than 4*a*–7*a*. Hence reheating increases the power output. By reheating, the average temperature of heat addition is raised resulting in higher output and efficiency of the cycle. If reheat cycle is to be adopted then the pressure ratio must be high as at low pressure ratios, the thermal efficiency is lowered by reheating Fig. 9.14. Reheating reduces the airflow through the cycle resulting in decreased input to the compressor. For ideal reheating; the working fluid temperature after reheating is equal to the maximum permissible turbine inlet temperature. That is, T5 = T3

The efficiency of the cycle will be given as,

$$\eta_t = \frac{(T_3 - T_4) + (T_5 - T_6) - (T_2 - T_1)}{(T_3 - T_2) + (T_5 - T_4)}$$

COGENERATION

Decentralized combined heat and power production-cogeneration is a very flexible and efficient way of utilizing fuels. Cogeneration based on biomass is environmentally friendly, and all kinds of biomass resources can be used. The role combined heat and power production plays in Danish energy supply originates from the decision in 1978 to establish a national natural gas grid. At present the natural gas system is one factor blocking the utilization of biomass and natural gas in decentralized cogeneration plants, because a great part of the heat market is lost for decentralized cogeneration due to the individual gas supply.

In June 1986 it was decided that 450 mW decentralized heat and power plants should be established.

These are very efficient and environmentally compatible, if they are based on natural gas or biomass. The interest in biomass as basis for combined heat and power production is caused partly by environmental considerations, and partly by the desire in agriculture and forestry to get rid of an increasing surplus of residue products, typically straw and wood chips. But exceeding the problem with an insufficient heat market, the energy policy has caused that until now there has been no sufficiently purposeful and ambitious aiming at the cogeneration technologies,that first of all shall lead to an increased use of biomass in heat and power supply.

Gas Turbines.

Some larger district heating plants have based their heat and power production on gas turbines. They can be regulated less than gas engines, and as they by mean of their size presuppose a large heat demand there will not be space for many new in the future. There are simply not that many cities with a sufficiently large heat demand. Apparently there is neither any product development-taking place to increase the power efficiency, as it is the case for gas engines.

Combined heat and power production based on steam

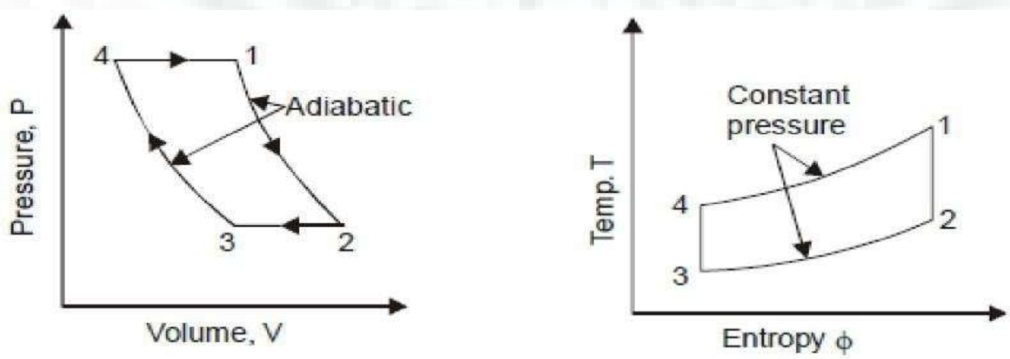
The Danish effort to increase the use of biomass mainly straw and wood as fuel in combined heat and power production increasingly draws the attention towards steam engines and steam turbines.

The steam engine is a well-known technology, but for different reasons it hasn't been developed for several years. One of the problems has been the contact between lubricating oil and steam. This problem has been solved with a new design of the steam generator, which is manufactured in Denmark and is just ready for the market. The advantage of this cogeneration technology is that biomass can be combusted directly in the steam boiler and obtain the wanted steam pressure of 20-30 bars. The disadvantage is that power efficiency will hardly exceed 15%. Therefore it is a question if the steam engine is able to compete with cogeneration based on gasified biomass in the longer term. There seem to be better possibilities for steam turbines with a combination of direct stoking of biomass in the boiler, and superheating of the steam with natural gas. A Danish district heating plant is preparing a test plant based on this technology. Its advantage is significantly higher power efficiency than the steam engine.

GAS TURBINE EFFICIENCY

Gas turbines may operate either on a closed or on an open cycle. The majority of gas turbines currently in use operate on the open cycle in which the working fluid, after completing the cycle is exhausted to the atmosphere. The air fuel ratio used in these gas turbines is approximately 60:1. The ideal cycle for gas turbine is Brayton Cycle or Joule Cycle. This cycle is of the closed type using a perfect gas with constant specific heats as a working fluid. This cycle is a constant pressure cycle and is shown in Fig. 9.24. On P-V diagram and in Fig. 9.25 on T-φ diagram. This cycle consists of the following processes:

The cold air at 3 is fed to the inlet of the compressor where it is compressed along 3-4 and then fed to the combustion chamber where it is heated at constant pressure along 4- 1. The hot air enters the turbine at 1 and expands adiabatically along 1-2 and is then cooled at constant pressure along 2-3.



Heat supplied to the system = $K_p(T_1 - T_4)$

Heat rejected from the system = $K_p(T_2 - T_3)$

where K_p = Specific heat at constant pressure,

Work done = Heat supplied – Heat rejected

$= K_p(T_1 - T_4) - K_p(T_2 - T_3)$

Thermal efficiency (η) of Brayton Cycle

$$\eta = \frac{\text{Work done}}{\text{Heat Supplied}} = \frac{[K_1\{(T_1 - T_4) - (T_2 - T_3)\}]}{[K_p(T_1 - T_4)]}$$

$$\eta = 1 - \frac{(T_2 - T_3)}{(T_1 - T_4)} \quad \text{...(1)}$$

For expansion 1-2

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}$$

$$T_1 = T_2\left[\left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}\right]$$

For compression 3-4

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{(\gamma-1)/\gamma} = \left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}$$

$$T_4 = T_3\left[\left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}\right]$$

Substituting the values of T_1 and T_4 in equation (1), we get

$$\eta = 1 - \frac{(T_2 - T_3)}{\left[\left\{T_2\left(\left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}\right)\right\} - \left\{T_3\left(\left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}\right)\right\}\right]}$$

$$\eta = 1 - \frac{(T_2 - T_3)}{\left[\left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}(T_2 - T_3)\right]}$$

CHAPTER - 5
HYDEL POWER PLANTS

INTRODUCTION

When rain water falls over the earth's surface, it possesses potential energy relative to sea or ocean towards which it flows. If at a certain point, the water falls through an appreciable vertical height,this energy can be converted into shaft work. As the water falls through a certain height, its potential energy is converted into kinetic energy and this kinetic energy is converted to the mechanical energy by allowing the water to flow through the hydraulic turbine runner. This mechanical energy is utilized to run an electric generator which is coupled to the turbine shaft. The power developed in this manner is given as:

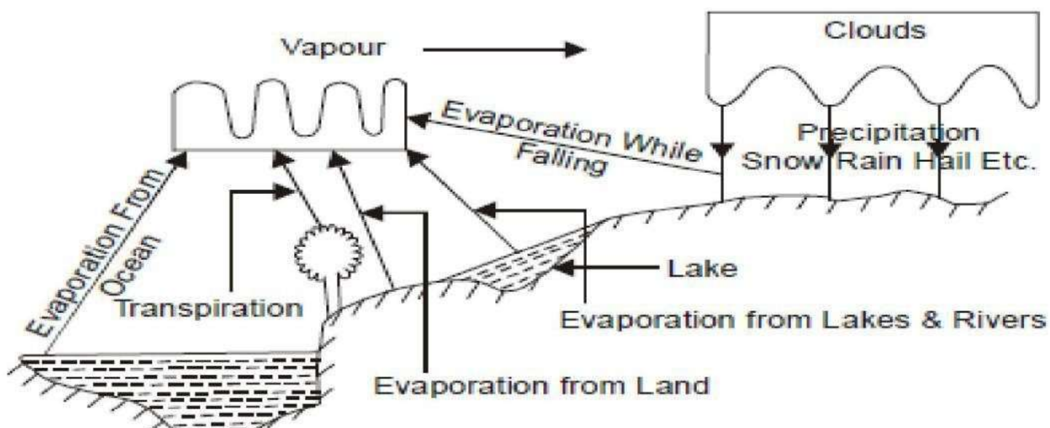
Power = W.Q.H.η watts ...(1)

where W = Specific weight of water, N/m3

Q = rate of water flow, m3/sec.

H = Height of fall or head, m

η = efficiency of conversion of potential energy into mechanical energy.



The generation of electric energy from falling water is only a small process in the mighty heat power cycle known as "Hydrological cycle" or rain evaporation cycle". It is the process by which the moisture from the surface of water bodies covering the earth's surface is transferred to the land and back to the water bodies again. This cycle is shown in Fig.. The input to this cycle is the solar energy. Due to this, evaporation of water takes, lace from the water bodies. On cooling, these water vapours form clouds. Further cooling makes the clouds to fall down in the form of rain, snow, hail or sleet etc; known as precipitation. Precipitation includes all water that falls from the atmosphere to the earth's surface in any form. Major portion of this precipitation, about 2/3rd, which reaches the land surface is returned to the atmosphere by evaporation from water surfaces, soil and vegetation and through transpiration by plants. The remaining precipitation returns ultimately to the sea or ocean through surface or
underground channels. This completes the cycle. The amount of rainfall which runs off the earth's land surface to form streams or 'rivers is useful for power generation. The precipitation that falls on hills and mountains in the form of snow melts during warmer weather as run- off and converges to form streams can also be used for power generation.

Hydro projects are developed for the following purposes:

1. To control the floods in the rivers.
2. Generation of power.
3. Storage of irrigation water.
4. Storage of the drinking water supply.

SELECTION OF SITE FOR A HYDRO-ELECTRIC POWER PLANT

While selecting a suitable site, if a good system of natural storage lakes at high altitudes and with large catchment areas can be located, the plant will be comparatively economical. Anyhow the essential characteristics of a good site are: large catchment areas, high average rainfall and a favourable place for constructing the storage or reservoir. For this purpose, the geological, geographical and meteorological conditions of a site need careful investigation. The following factors should be given careful consideration while selecting a site for a hydro-electric power plant:

1. Water Available.

To know the available energy from a given stream or river, the discharge flowing and its variation with time over a number of years must be known. Preferably, the estimates of the average quantity of water available should be prepared on the basis of actual measurements of stream or river flow. The recorded observation should be taken over a number of years to know within reasonable, limits the maximum and minimum variations from the average discharge. the river flow data should be based on daily, weekly, monthly and yearly flow ever a number of years. Then the curves or graphs can be plotted between tile river flow and time. These are known as hygrographs and flow duration curves.The plant capacity and the estimated output as well as the need for storage will be governed by the average flow. The primary or dependable power which is available at all times when energy is needed will depend upon the minimum flow. Such conditions may also fix the capacity of the standby plant. The, maximum of flood flow governs the size of the headwords and dam to be built with adequate spillway.

2. Water-Storage.

As already discussed, the output of a hydropower plant is not uniform due to wide variations of rain fall. To have a uniform power output, a water storage is needed so that excessflow at certain times may be stored to make it available at the times of low flow. To select the site of thedam ; careful study should be made of the geology and topography of the catchment area to see if thenatural foundations could be found and put to the best use.

3. Head of Water.

The level of water in the reservoir for a proposed plant should always be within limits throughout the year.

4. Distance from Load Center.

Most of the time the electric power generated in a hydro-electricpower plant has to be used some considerable distance from the site of plant. For this reason, to beeconomical on transmission of electric power, the routes and the distances should be carefully considered since the cost of erection of transmission lines and their maintenance will depend upon the routeselected.

5. Access to Site.

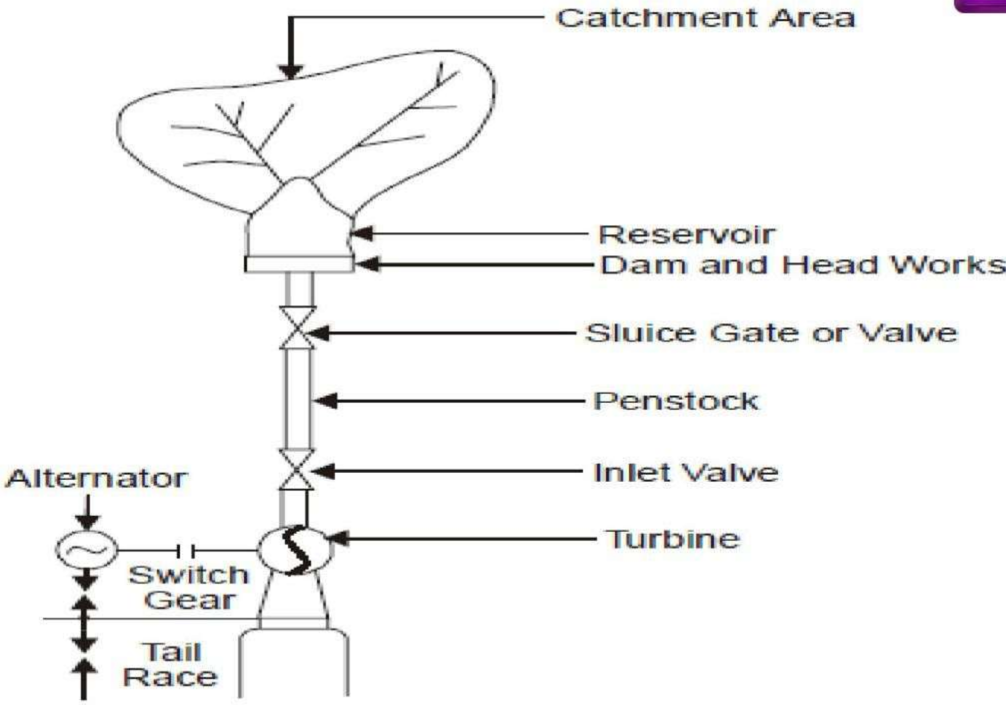
It is always a desirable factor to have a good access to the site of the plant. This factor is very important if the electric power generated is to be utilized at or near the plant site. Thetransport facilities must also be given due consideration.

ESSENTIAL FEATURES OF A WATER-POWER PLANT

A simplified flow sheet of a water power plant is shown in Fig.

The essential features of a water power plant are as below:

1. Catchment area.
2. Reservoir.
3. Dam and intake house.
4. Inlet water way.
5. Power house.
6. Tail race or outlet water way.



1. **Catchment Area.**

The catchment area of a hydro plant is the whole area behind the dam, draining into a stream or river across which the dam has been built at a suitable place.

2. **Reservoir.**

Whole of the water available from the catchment area is collected in a reservoir behind the dam. The purpose of the storing of water in the reservoir is to get a uniform power output throughout the year. A reservoir can be either natural or artificial. A natural reservoir is a lake in high mountains and an artificial reservoir is made by constructing a dam across the river.

3. **Dam and Intake House.**

A dam is built across a river for two functions: to impound the river water for storage and to create the head of water. Dams may be classified according to their structural materials such as: Timber, steel, earth, rock filled and masonry. Timber and steel are used for dams of height 6 m to 12 m only. Earth dams are built for larger heights, up to about 100 m. To protect the dam from the wave erosion, a protecting coat of rock, concrete or planking must be laid at the water line. The other exposed surfaces should be covered with grass or vegetation to protect the dam from rainfall erosion. Beas dam at Pong is a 126.5 m high earth core-gravel shell dam in earth dams, the base is quite large as compared to the height. Such dams are quite suitable for a pervious foundation because the wide base makes a long seepage path. The have got the following

EARTH DAMS - ADVANTAGES.

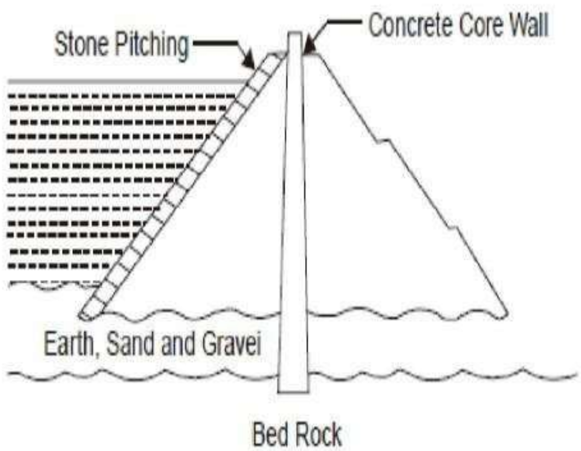
(a) Suitable for relatively pervious foundation.
(b) Usually less costlier than a masonary dam.
(c) If protected from erosion, this type of dam is the most permanent type of construction.
(d) It fits best in natural surroundings.

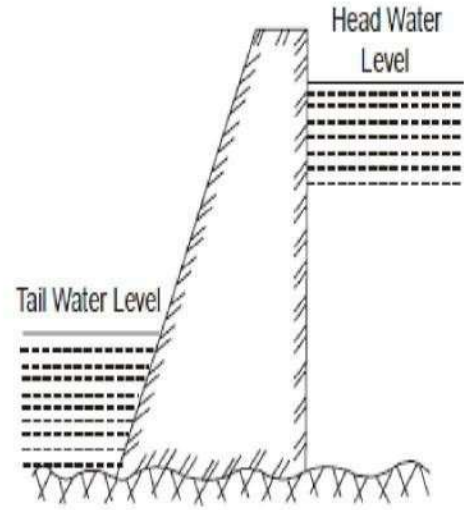
EARTH DAMS - DISADVANTAGES OF:

(a) Greater seepage loss than other dams.

(b) The earth dam is not suitable for a spillway, therefore, a supplementary spillway is required.

(c) Danger of possible destruction or serious damage from erosion by water either seeping throughit or overflowing the dam.





The masonary dams are of **three major classes**:

1. Solid gravity dam,
2. Buttress dam and
3. The arched dam.

The buttress or deck dam has an inclined upstream face, so that water pressure creates a large downward force which provides stability against overturning or sliding. An arch dam is preferablewhere a narrow canyon width is available. It can be anchored well and the water pressure against thearch will be carried by less concrete than with a straight gravity type.This dam has the inherent stabilityagainst sliding. The most commonly used dams are shown in figure.

Dams must be able to pass the flood water to avoid damage to them. This may be achieved by spillways, conduits piercing the dam and the tunnels by passing the dam.

The intake includes the head works which are the structures at the intake of conduits, tunnels or flumes. These structures include booms, screens or trash racks, sluices for bypassing debris, and gates or valves for controlling the water flow. Booms prevent the ice and floating logs from going into the intake by diverting them to a bypass chute. Booms consist of logs tied end to end and form a floating chain. Screens or trash racks are fitted directly at the intake to prevent the debris from going into the intake. Debris cleaning devices should also be fitted on the trash racks. Gates and valves control the rate of water flow entering the intake.

The different types of gates are radial gates, sluice gates, wheeled gates, plain sliding gates, crest gates, rolling or drum gates etc. The various types of valves are rotary, spherical, butterfly or needle valves. A typical intake house is shown in Fig. . An air vent should be placed immediately below the gate and connected to the top of the penstock and taken to a level above the head water. When the head gates are closed and the water is drawn off through the turbines, air will enter into the penstock through the air vent and prevent the penstock vacuum which otherwise may cause collapsing of the pipe. A filler gate is also provided to balance the water pressure for opening the gate.

4. Inlet Water Ways.

Inlet water ways are the passages, through which the water is conveyed to the turbines from the dam. These may include tunnels, canals, flumes, for bays and penstocks and also surge tanks. A fore bay is an enlarged passage for drawing the water from the reservoir or the river and giving it to the pipe lines or canals.

Tunnels are of two types: pressure type and non-pressure type.

The pressure type enables the fall to be utilized for power production and these are usually lined with steel or concrete to prevent leakages and friction losses. The non- pressure type tunnel acts as a channel. The use of the surge tank is to avoid water hammer in the penstock. Water hammer is the sudden rise in pressure in the penstock due to the shutting off the water to the turbine. This sudden rise in pressure is rapidly destroyed by the rise of the water in the surge tank otherwise it may damage or burst the penstock.

5. Power House.

The power house is a building in which the turbines, alternators and the auxiliary plant are housed.

6. Tail Race or Outlet Water Way.

Tail race is a passage for discharging the water leaving the turbines, into the river and in certain cases, the water from the tail race can be pumped back into the original reservoir.

CLASSIFICATION OF HYDRO-PLANT

In hydro-plants, water is collected behind the dam. This reservoir of water may be classified aseither storage or pondage according to the amount of water flow regulation they can exert. The functionof the storage is to impound excess river flow during the rainy season to supplement the low rates offlow during dry seasons. They can meet the demand of load fluctuations for six months or even for ayear. Pondage involves in storing water during low loads so that this water can be utilized for carryingthe peak loads during the week. They can meet the hourly or weekly fluctuations of load demand. Withpoundage, the water level always fluctuates during operations It rises at the time of storing water, falls atthe time 'off drawing water, remains constant when the load is constant.

The hydro-power plants can be classified as below:

l. Storage plant
  (a) High head plants
  (b) Low head plants
  (c) Medium head plants.
2. Run-of-river power plants
  (a) With pondage
  (b) Without pondage.
3. Pumped storage power Plants.

STORAGE PLANTS

These plants are usually base load plants. The hydro-plants cannot be classified directly onthe basis of head alone as there is no clear line of demarcation between a high head and a medium heador between medium head and low head. The power plant can be classified on the basis of head roughlyin the following manner:

(a) **High head plants.** About 100 m and above.
(b) **Medium head plants.** about 30 to 500 m.
(c) **Low head plants.** Upto about 50 m.

High Head Plants.

Fig. shows the elevation of a high head plant. The water is taken fromthe reservoir through tunnels which distribute the water to penstock through which the water is conveyedto the turbines. Alternately, the water from the reservoir can be taken to a smaller storage knownas a forbay, by mans of tunnels. From the forbay, the water is then distributed to the penstocks. Thefunction of the forbay is to distribute the water to penstocks leading to turbines. The inflow to thefore bay is so regulated that the level in the forbay remains nearly

constant. The turbines will thus be fedwith under a constant static head. Thus, the forbays help to regulate the demand for water according tothe load on the turbines. Trash racks are fitted at the inlets of the tunnels to prevent the foreign matterfrom going into the tunnels. In places; where it in not possible to construct forbays, vertical constructionsknown as `surge tanks' are built. The surge tanks are provided before the valve house and after thetunnel from the head works. The function of the surge tank is to prevent a sudden pressure rise in thepenstock when the load on the turbines decreases and the inlet valves to the turbines are suddenly closed. In the valve house, the butterfly valves or the sluice type valves control the water flow in thepenstocks and these valves are electrically driven. Gate valves are also there in the power house tocontrol the water flow through the turbines,after flowing through tile turbines . The water is dischargedto the tail race.

Low head power plants.

These power plants are also known as canal power plants. Such a Plant is shown in fig. A dam is built on the river and the water is diverted into a canal which conveys the water into a Forbay from where the water is allowed to flow through turbines. After this, the water is again discharged Into the river through a tail race. At the mouth of the canal, head gates are fitted to control the Flow in the canal. Before the water enters the turbines from the forbay. It is made to flow through Screens or trash-racks so that no suspended matter goes into the turbines. If there is any excess water due To increased flow in the river or due to decrease of load on the plant, it will flow over the top of the dam Or a *waste weir can be constructed* along the forbay so that the excess water flows over it into the river. For periodic cleaning and repair of the canal and the forbay, a drain gate is provide on the side of the Waste weir. The head gate is closed and the *drain gate* is opened so that whole of the water is drawn from Theforbay and the canal for their cleaning and repair.

Medium Head Plants.

If the head of water available is more than 50 m., then the water from the forbay is conveyed to the turbines through pen-stocks. Such a plant will then be named as a medium head plant. In these plants, the river water is usually tapped off to a forbay on one bank of the river as in the case of a low head plant. From the forbay, the water is then led to the turbines through penstocks. Such a layout is shown in Fig.

RUN-OF-RIVER POWER PLANTS

These plants can be classified as either without pondage or with pondage. A run-of-river plant without pondage has no control over river flow and uses the water as it comes. These plants usually supply peak load. During floods, the tail water level may become excessive rendering the plant inoperative.

A run-of-river plant with pondage may supply base load or peak load power. At times of high water flow it may be base loaded and during dry seasons it may be peak loaded.

PUMPED STORAGE POWER PLANTS

These plants supply the peak load for the base load power plants and pump all or a portion of their own water supply. The usual construction would be a tail water pond and a head water pond connected through a penstock. The generating pumping plant is at the lower end. During off peak hours, some of the surplus electric energy being generated by the base load plant, is utilized to pump the water from tail water pond into the head water pond and this energy will be stored there. During times of peak load, this energy will be released by allowing the water to flow from the head water pond through the water turbine of the pumped storage plant. These plants can be used with hydro, steam and i.e. engine plants. This plant is nothing but a hydraulic accumulator system and is shown in Fig. . These plants can have either vertical shaft arrangement or horizontal shaft arrangement. In the older plants, there were separate motor driven pumps and turbine driven generators. The improvement was the pump and turbine on the same shaft with the electrical element acting as either generator or

motor. The latest design is to use a Francis turbine which is just the reverse of centrifugal pump. When the water flows through it from the head water pond it will act as a turbine and rotate the generator. When rotated in the reverse direction by means of an electric motor, it will act as a pump to shunt the water from the tail water pond to the head water pond.

The efficiency of such a plant is never 100 per cent. Some water may evaporate from the headwater pond resulting in the reduction in the stored energy or there might be run off through the soil.

ADVANTAGES AND DISADVANTAGES OF UNDERGROUND POWER-HOUSE

Advantages

1. Under suitable geological conditions, the underground conduit may prove the shortest and sometimes even straight. The power conduit may be much shorter than the length of power canal used for underground power house as the power canal usually built to follow the contours of the terrain. By locating the power house underground, the number of restrictions as safe topographical and geological conditions along the penstock and sufficient space at the foot of the hill for constructing the power house are completely eliminated.

2. The construction of underground conduit instead of penstock results in considerable saving in steel, the internal pressure is carried partly by the rock if it is of good quality. In sound high quality rock, the penstock is replaced by an inclined or vertical pressure shaft excavated in rock and provided with a steel lining of greatly reduced thickness in comparison with exposed penstock 'roe purpose' of lining in such cases is protection against the seepage losses.
3. The reduced length of the pressure conduit reduced the pressures developed due to waterhammer. Therefore, smaller surge tank is also sufficient.
4. For the economical arrangement, the ratio of the pressure conduit to the tail-race tunnel is also significant. The overall cost of the system is lower if the tail-race tunnel length is relatively large.
5. The construction work at underground power station can continue uninterrupted even under severest winter conditions. The overall construction cost and period of construction is reduced due to continuity of work.
6. Much care is devoted today in many countries to preserve landscape features such as picturesque rock walls, canyons, valleys and river banks in their original beauty against spoiling by exposed penstocks, canal basins and machine halls. There is less danger of disturbance to amenities with an underground power house and pipelines. The other advantages gained by constructing underground power house are listed below. The six advantages mentioned above reduce the constructional difficulties and overall cost of the plant and preserve the original beauty of landscape. The overall cost is further reduced by the modern techniques in tunnel work and better excavation process.
7. The shorter power conduit of underground power house reduces the head losses.
8. The regular maintenance and repair costs are lower for underground stations as the maintenancerequired for rock tunnels is less.
9. The power plant is free from landslides, avalanches, heavy snow and rainfall.
10. The useful life of the structures excavated in rock is considerably longer than that of concrete and reinforced concrete structures.
11. It is possible to improve the governing of the turbines with the construction of underground power house.
12. The construction period is reduced mainly due to the possibility of full-scale construction work in winter.
13. Underground power station is bomb-proof and may be preferred for military reasons: They are perfectly protected against air-raids. The military considerations became more predominant with the increased shadow of the war and the building of underground power stations underwent a rapid evolution after second world war.

Disadvantages

1. The construction cost of the underground power house is more compared with the over ground power house :

(a) The excavation of the caverns required for housing the turbine generator units and auxiliaryequipments (machine hall of Koyna project is $00′ × 120′ × 60′ in dimensions) is very expensive.

(b) The costs of access tunnels are considerable.

(c) The separate gallery excavated for the inlet valves adds the extra cost.

(d) The construction of air ducts and bus galleries also adds in total construction costs.

(e) Special ventilation and air-conditioning equipment required for underground adds in the constructionalcosts.

(f) In some cases, the tailrace tunnel of an underground power house requires a moreelaboratesolution than a tailrace tunnel designed for the surface arrangement. The advantage gained byreducing the pressure conduit would be lost by extending the tailrace tunnel.

(g) The first cost is also increased by locating the transformer and high-voltage switchgear underground.

The above-mentioned constructions increase the capital cost of the plant.

2. The operational cost of the power plant increases due to following reasons :

(a) The lighting cost.

(b) The running cost of air-conditioned plant.

(c) The removal of water seeping may be more costly than for the surface arrangement.

Adequate lighting, proper ventilation, maintenance of uniform climatic conditions within thepower houses, provision of the necessary safety equipments against flooding, maintenance of properacoustical conditions, augmenting the feeling of safety by providing a sufficient number of well placedexit; and finally artistic shaping and outfitting of machine hall increases the overall cost of the undergroundpower house compared with ground surface power house.

The choice of the site for the power house either over ground or underground requires a considerable economical analysis according to the available topography and no thumb rule can be applied for its selection.